APPLICATION OF FERROGRAPHY IN WEAR CONDITION MONITORING OF AN AUTOMOBILE SYSTEM

By

UMESH MUTTUR

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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DEDICATED
TO
MY PARENTS

CERTIFICATE

Certified that this work on 'Application of Ferrography in Wear Condition Monitoring of an Automobile System' by Sri Umesh Muttur in partial fulfilment of the requirements for the Degree of Master of Technology of the Indian Institute of Technology, Kanpur, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

April, 1985

(M.K. MUJU)
Assistant Professor
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur
KANPUR

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UMESH MUTTUR

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

DR	-	Direct reading
D_L	-	Large particle reading in the Direct Reading Ferrograph
D_S	-	Small particle reading in the Direct Reading Ferrograph
R_L	-	Large Particle Reading given by the 'Ferrogram Reader' in the Ferroscope
R_S	-	Small Particle Reading given by the 'Ferrogram Reader in the Ferroscope
R_X	-	Ferrogram Reading at any position X on the Gerrogram
WPC	-	Wear Particle Concentration. It has also been called as Total Wear in the text.
%LP	-	Percentage Large Particles
SWI	-	Severity of Wear Index
[illegible]	-	Wear Index
AUC	-	Area under the Curve
n	-	Dilution factor
n_1	-	Volume of liquid run in the Ferrograph for the test
A_X	-	Percentage Area Covered Reading for a segment 'X'.

ABSTRACT

This study was conducted to test the feasibility of application of Ferrography Technique to wear studies of a service unit. A transport vehicle which was easily accessible was selected as a test unit for the purpose. Samples of lubricating oil were collected at regular intervals and were studied using the Ferrographic analysis.

Ferrography is a recent technique applied in the field of tribology for condition monitoring of expensive equipments which can not be easily stopped for the purpose of wear studies.

The analysis of various test samples reflected the conditions of the machinery and helped to make suggestions for oil change. It was observed that in general, the timings for suggested oil changes tallied with manufacturer's guide lines.

CHAPTER - I

1.1 Introduction:

In the recent years, there has been an increasing awareness throughout industry of the importance of tribology. The material and energy conservation is becoming a major aspect of machine design. Wear is a major cause of material wastage. Hence there is an urgent need to probe into the mechanism of wear of machine parts and to find some method of measuring the wear.

There are a number of systems in industry today, which operate continuously e.g. power generation and process industries. Here, the conventional method of studying the surfaces to understand the nature and extent of wear, cannot be applied without bringing the system to a stop. This is a heavy strain on the economy of the system. This gives rise to the necessity of a method which can determine the condition of machinery while in service, and to detect any deterioration of performance so that remedial action can be taken before the breakdown point is reached. The present work is a step in that direction. The technique used here is " FERROGRAPHY". Ferrography

is a new method in which wear particles are separated from the lubricant and deposited on a glass substrate for microscopic examination and subsequent analysis.

1.2 Nature of Wear:

Wear can be defined as " the progressive loss of substance from the operating surface of a body occurring as a result of relative motion at the surface".

The rate at which a material is removed by wear will depend upon the working conditions e.g. loading, lubrication and environment. A large number of variables are involved in a wearing process. Hence it is difficult to arrive at any generalisation. That is each wear study is very much individual in character and there is as yet no fundamental theory covering all the types of wear.

1.3 Different types of wear can be identified. They are

(i) Abrasive wear (ii) Adhesive wear
(iii) Wear due to fatigue (iv) Fretting wear
(v) Erosive wear (vi) Wear due to chemical action.

1.3.1 Abrasive Wear :- In practice all surfaces have some degree of roughness and hence the mating surfaces in relative motion will abrade each other. The wear debris thus formed will join in the process. Abrasion is virtually a cutting action and brought about by the

loose hard particles sliding between two mating surfaces. Or it may be due to particles merely rubbing against a surface. It may also arise when one of the surfaces is itself rough.

1.3.2 Adhesion Wear:- Adhesive forces between surfaces arise from atomic attraction and result in local cold welding of neighbouring asperities. Because of the relative motion between the mating surfaces, the welds are sheared. This shearing accounts for the frictional forces. Because of the shearing there will be transfer of material from one surface to the other. The particle of removed material finally breaks away and forms a part of the debris.

Very severe adhesive wear resulting in gross surface damage is known as 'scuffing'.

1.3.3 Fatigue Wear:- This type of wear is found in cases where the mating elements are subjected to dynamic loading. Journal bearing shells may fail due to fatigue. It is quite common in gears and ball and roller bearings. Balls and rollers are subject to very high alternating stresses and when these are above the endurance limit, small cracks will result, followed by pitting and spalling.

1.3.4 Fretting Wear:- This is a specific form of wear

which occurs when there is slight vibratory movement between loaded surfaces in contact and which manifests itself by pitting of the surfaces and the accumulation of oxidised debris. Examples of fretting wear are clamped or bolted assemblies and parts such as splines and ball and roller bearings which are subjected to vibration either in operation or during transport, or bundle of tubes in close proximity particularly in chemically active medium as in reactors.

1.3.5 Erosive Wear:- Erosive wear is that due to impact of particles e.g. sand blasting. The process is a combination of deformation and cutting. Other examples of this form of wear are erosive wear of nozzles and blades of gas turbines due to solid particles in the products of combustion.

1.3.6 Chemical Wear:- Chemical wear is associated with other forms of wear. The carburation and oxidation of wear debris are stages in complete wear of other forms.

Corrosion wear is a form of chemical wear which results from the interaction of the environment with sliding surfaces followed by the rubbing off of the products of the reaction.

1.4 Machinery Condition Monitoring:

Withdrawing equipment from service for periodic inspection and maintenance can be replaced by failure prevention maintenance. Condition monitoring is a (1) practice developed to determine the condition of the machinery while in service and to detect any deterioration of performance so that remedial action can be taken before the breakdown point is reached. Maintenance carried out when required after a significant deterioration in a component as indicated by a sensor or monitored parameter is called " on-condition maintenance".

There are basically four techniques for the monitoring of plant and machinery deterioration,

(i) dynamic methods e.g. vibration monitoring

(ii) inspection/integrity surveillance methods which include non-destructive testing techniques besides other methods

(iii) contaminant inspection

(iv) trends analysis.

Of all these techniques, contaminant inspection is found to be very versatile and also quite simple as regards to instrumentation.

In a lubricated system the wear debris particles are in suspension in the circulating oil, the size and

rate of generation of which increase as the rate of wear increases. By identifying and measuring these metallic particles, the surface from which the particles were worn can be identified and the rate of wear can be determined to be normal or abnormal.

The different techniques used in oil condition monitoring are

i) Magnetic plug inspection

ii) Spectrometric Oil Analysis Procedure [SOAP]

iii) Particle counting (for hydraulic fluids)

iv) Patch testing

v) Ferrography.

1.4.1 Magnetic plug inspection:- In this method, a magnetic plug incorporating a non-return valve is used. It can be inserted into a pipe line and/or withdrawn without loss of fluid. Debris which has been trapped by such a magnetic plug can be measured with a magnetometer to determine the amount that has been collected. At the same time, examination under a microscope and comparison with Debris recognition drawings makes it possible to tell the component from which the major amount of wear material has arisen.

1.4.2 Spectrometric Oil Analysis:- In this method, the oil sample is burnt in a flame, the spark of the emission

or absorbtion spectrometer breaks the compounds and each element displays its individual set of spectrum lines. To detect and measure the quantity of an element, standard solutions of that element with different concentrations are used. Then the concentration of the unknown sample is calibrated. The main advantages of this method are that it can detect and measure the quantity of an element present in the sample, independently of how the element is incorporated in a compound and a wide variety of contaminants like air dirt, assembly or repair debris, system wear metals, corrosion products etc. can be detected.

1.4.3 Particle Counting:- This is mainly used for hydraulic systems where cleanliness requirements are quite high. Analysing particulate contamination is usually carried out by particle count methods utilising either microscopes or automatic counters. These methods count particles retained on a membrane surface after the fluid sample has been filtered. These methods are, however, time consuming.

1.4.4 Patch Test Procedure:- The typical colour of contamination in any given hydraulic system remains fairly constant. The darkness of the particle discolouration of a filter is a rough indication of the

cleanliness of the test fluid. This method is only generally applicable to gross levels of contamination.

1.4.5 Ferrography:- This is a technique to separate and precipitate magnetic and paramagnetic particles from the lubricating oil for microscopic examination and subsequent analysis. It has emerged as a convenient method for the isolation and analysis of wear particles and has opened up a new dimension in wear detection and assessment in the form of particle tribology. Recent developments have enabled the adoption of ferrography to bio-engineering for the study of prosthesis joints.

A detailed account of this rapidly growing technique is presented in following section.

1.5 Objective and Scope of the Present Work:

The present work on wear monitoring technique has been conducted on I.C. Engines using 'Duplex Ferrograph Analyzer'. This unit is one of the most recent equipments which is being used in industry for the purpose of wear monitoring. The work involved in the present case constitutes (i) setting up and commissioning of the recently procured equipment, (ii) selection of suitable system for the wear study (iii) conducting the necessary Ferrographic Analysis on the lubricating oil samples from the system under study.

Three case studies have been presented in this work

(i) Tata 1210 SE Bus - engine

(ii) Tata 1210 SE Bus - Gear box

(iii) Bajaj Chetak Scooter-Gear box.

In all these cases, extensive work on quantitative aspects of Ferrography was done. An attempt was also made to study the qualitative nature of wear behaviour. In the broader objective of the work, it was intended to include 'Proton Induced X Ray Emission (PIXE) and/or Spectrographic Oil Analysis Procedure' (SOAP) analyses to corroborate the ferrography results. However, due to repeated failure of these units during the current work, these techniques could not be available. Much larger information could have been obtained about the type of wear with the help of 'Wear Atlas' - a patented technical guide also marketed by the manufacturers of the equipment. It is hoped that for future research this facility will be available.

CHAPTER - II

FERROGRAPHY - A WEAR MONITORING TECHNIQUE

2.1 Principles of Ferrography:

Ferrography in loose terms means " Iron writing" - The name 'Ferrography' arises from the original purpose of the technique, which was the magnetic precipitation of ferrous wear particles from lubricating oil.

There are two types of analysis in Ferrography.

(1) The quantitative analysis which concerns more with the numerical data of wear debris. Here some sort of numerical 'wear index' is calculated to express the wear condition.

(2) Qualitative analysis is connected with the study of the particle size and shape. Particles are analysed under a microscope and the particle material is identified.

Accordingly, there are two instruments available for ferrographic analysis.

(a) The Direct Reading (DR) Ferrograph

(b) The Analytical Ferrograph

2.1.1 The Direct Reading Ferrograph:

The direct reading ferrograph can be used for routine checks. In this instrument the presence of particles is sensed by using a light attenuation technique (Fig. 2.1). A high gradient magnetic field precipitates wear particles in a glass tube at a position dependent upon their size. Provided the concentration of particles is not too great there is very little overlap of the deposited particles, and, the amount of light blocked by the particles, measured at two positions by the photocells, is proportional to their cross-sectional area. The readings from the two densitometers are loosely referred to as 'Large particle readings (D_L)' and small particle readings (D_S)' which are basically area covered by large particles (D_L) and area covered by small particles (D_S). Various terms are used to define the wear.

(i) Wear Particle Concentration (WPC) (2)

It is the sum of large particle reading and the small particle reading. i.e.

$$WPC = D_L + D_S$$

(ii) 'Severity of wear' is given by '$D_L - D_S$'

(iii) The "Percentage large particles" (PLP) is given (2) by

$$PLP = \frac{D_L - D_S}{D_L + D_S} \times 100$$

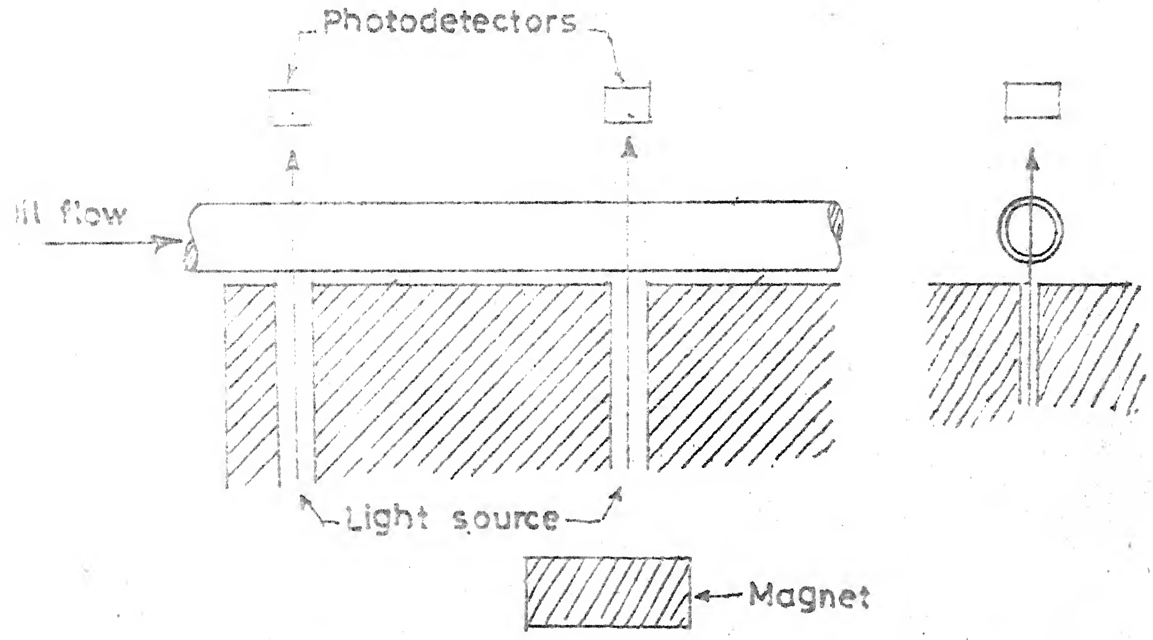

Fig.2.1 Direct Reading Ferrograph

(iv) 'Severity of Wear Index'. This index has been used (3) by many researchers to express the magnitude of wear. It is mathematically expressed as

$$\text{Severity of Wear Index SWI} = D_L \ (D_L - D_S)$$

(v) 'Wear Index' is the most popular index which has been used in many works. It is given by

$$\begin{aligned}\text{Wear Index WI} &= (D_L + D_S)\ (D_L - D_S) \\ &= (D_L^2 - D_S^2)\end{aligned}$$

<u>Normalization of Readings</u>: The wear particle concentration varies from sample to sample. In some samples the concentration may be so low that more oil has to be run through the analyzer for obtaining readings in the instrument range (DR Ferrograph). Or in some cases, the concentration of the wear particles may be so high that the readings may go beyond the range. In such cases, the samples are either diluted, or more quantity of the sample is used in order to get the readings. Then, there is a need to normalize the readings of different dilutions in order to compare them.

The normalizing is done as follows:

Suppose 1 ml of the sample oil is mixed with 4 ml of clean oil to produce a 5:1 dilution and 1 ml of this diluted sample is processed. Therefore the normalized sample size is 0.2 ml.

2.1.2 Analytical Ferrograph: The analytical ferrograph is used to prepare a 'ferrogram' which is subsequently examined using a bichromatic microscope.

A ferrogram (Fig. 2.2) is prepared by pumping(4) fluid through teflon tubing (C) by means of a peristaltic pump onto specially prepared microscope glass (A) which has a non-wetting barrier (B) painted on one surface to centrally channel the liquid. The ferrogram is mounted at a slight angle to the horizontal by resting on block (D), so that the fluid will flow, by gravity, along the glass, but within the barrier, where it is picked up by the drain tube (E). The teflon tubing is held in place by a delivery arm (F), and the ferrogram is held in place by a spring loaded pin (G). The ferrogram is mounted above two permanent magnets (H) and (I) which are separated by an aluminium sheet about 1/16" thick. The ferrogram is positioned such that the separating aluminium sheet (J) is under the middle of the fluid channel of the ferrogram. The magnets are separated with their magnetic poles counter placed, that is, where one magnet pole is considered north, the other magnet across the aluminium strip is south, such that a strong magnetic field gradient is created in the vertical direction above the aluminium strip. The magnetic particles in

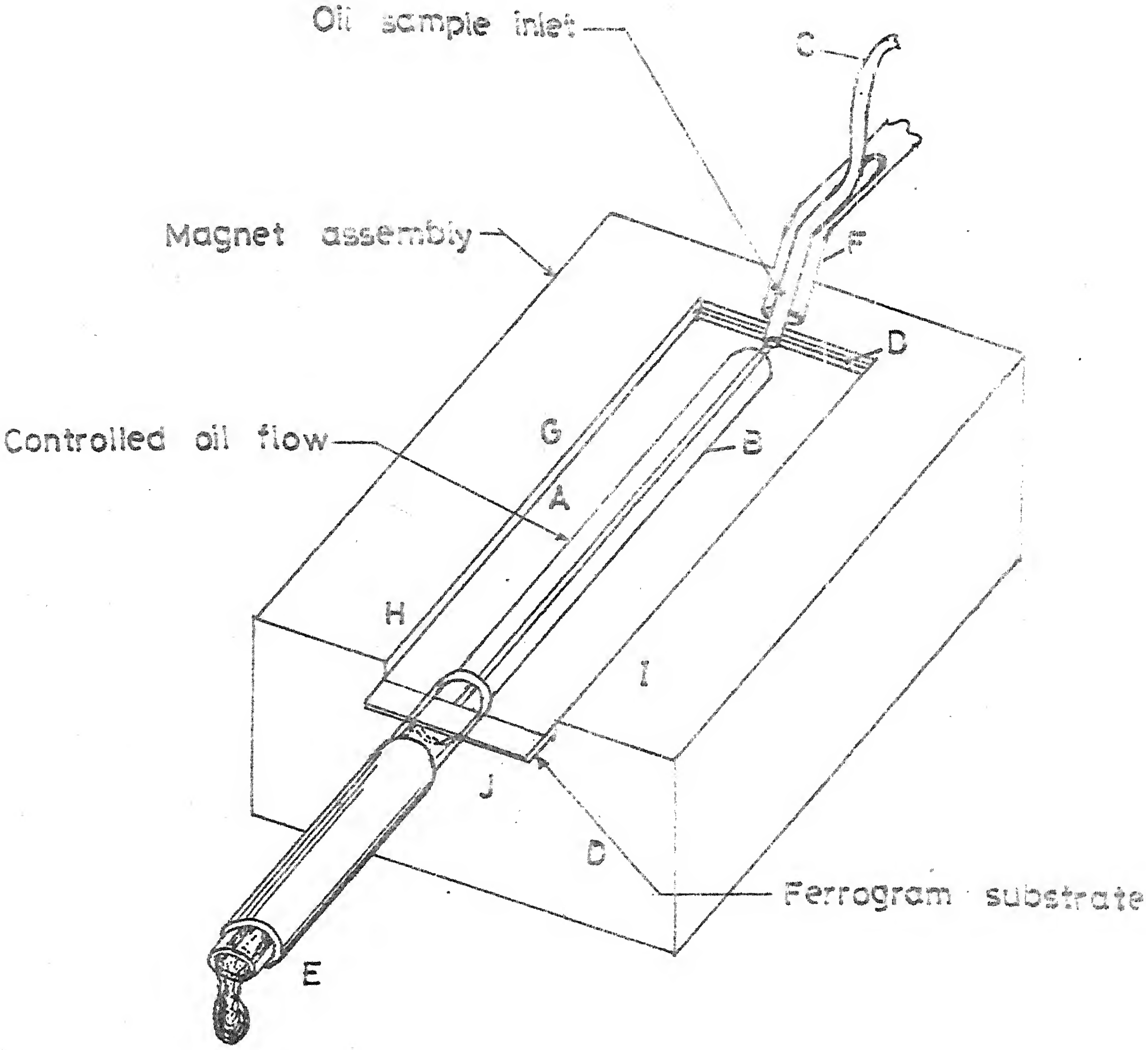

Fig.2.2 Apparatus for preparing Ferrogram

particles migrate through the fluid down to the glass surface where they are deposited in strings perpendicular to the direction of fluid flow. The strings are formed because particles align themselves with north to south pole, etc. The strings are separated from each other by some distance because particles will be mutually repulsed if an aligned particle is pulled down directly above another aligned particle. After the sample is run, a fixer solution is run across the ferrogram to remove residual fluid. After the fixer dries, which takes a few minutes, the ferrogram is ready for observation under the microscope.

A special microscope is used to examine ferrograms. It is equipped with both reflected and transmitted light sources which may be used simultaneously. When red reflected light and green transmitted light are used, this lighting scheme being called bichromatic illumination, the metal particles appear red and non-metal as green. The free metal particles will block the green light from below and reflect red light, whereas non-metals in thin sections will allow transmission of green light from below.(12)

Polarizers can also be used for both the light paths. Metallurgical (dry) objectives are used in the

microscope. The microscope is equipped with camera attachments and a ferrogram reader, which provides a mechanically determined light extinction measurement which corresponds to particle concentration at various locations. Readings for large particles and small particles can be obtained by the Reader also.

Particle Deposition:- Ferrous particles are deposited on a ferrogram according to size because the force acting on a particle is proportional to volume whereas the viscous resistance of the suspending fluid is proportional to surface area. Therefore, for spheres, force increases with the cube of the diameter, but resistance increases only with the square of the diameter. The largest ferrous particles are therefore deposited at the entry region of the ferrogram where the fluid, such as hydraulic oil, first touches down on the glass surface. Fig. (2.3) indicates a typical deposition. Near the entry end, ferrous particles larger than a characteristic size will be deposited. Near the exit end, ferrous particles greater than 0.02 μm will be deposited. For non-ferrous particles like Al, brass, white metal, etc. deposition occurs because of their weak magnetic property inherited by their association with magnetic particles. But, the deposition of these materials will be less size selective.

A quantitative measurement of the particle deposition on a ferrogram can be made, just as in the case of DR Ferrograph. (Fig. 2.3)

Here, the Ferrogram Reader is connected to the microscope. The reading at the entry deposit is recorded as 'R_L'. Then the ferrogram is moved through 5 mm towards the exit end and the reading is recorded as 'R_S'. These values are the % area covered by the debris on the ferrogram at the respective positions.

The various indices like Wear Index, Severity of Wear Index and % Large Particles are calculated in the same way as is done in DR analysis.

In addition, another quantitative term called the 'Area Under the Curve (AUC)' can be calculated for each ferrogram. The Reader readings are recorded at every 10 mm distance on the ferrogram, starting from the 10 mm point from the exit end. These readings are normalized for 1 ml of oil sample. This normalizing depends on the dilution of the oil and the volume of the sample used in preparing the ferrogram. Five segments are identified : 10 to 20 mm, 20 to 30 , 30 to 40, 40 to 50 and 50 to entry

$$\% \text{ Area segment } A_{10} = \frac{n}{n_1} \left(\frac{R_{10} + R_{20}}{2} \right) \times 10 \text{ mm}$$

Here n is the dilution factor.

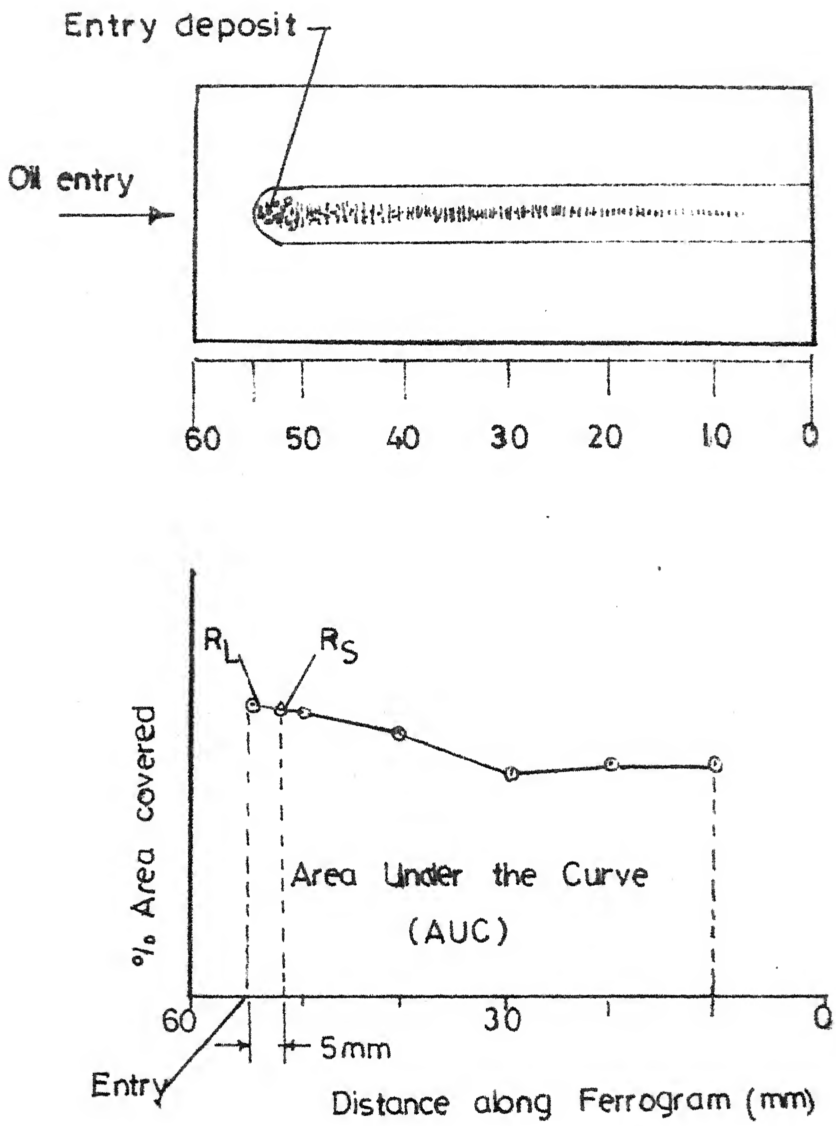

Fig. 2.3 Particle Deposition and 'Area Under The Curve'

And n_1 is the volume of sample run to make the ferrogram. Similarly other percentage area segments are calculated as A_{20}, A_{30}, etc.

Then AUC = $A_{10} + A_{20} + A_{30} + A_{40} + A_{50}$.

2.2 Scope of Ferrography:

The most popular techniques of wear debris analysis for machinery condition monitoring have been the spectrographic oil analysis procedure [SOAP], the magnetic plug method and now ferrography. Although SOAP and magnetic plugs have proved effective in providing warning of changes in a system, they have some disadvantages.

(i) SOAP provides a knowledge only of the quantity of metal in the lubricant but no information on the size or shape of the wear particles.

(ii) SOAP equipment is expensive.

(iii) There is a delay between sampling and analysis.

(iv) The technique is only sensitive to a very limited particle size. The maximum particle size limitation is around 10 μm depending upon the spectrometer and the experimental conditions. Just as SOAP suffers from an upper limit to the size of particle it can detect, magnetic plugs are to a large extent limited

to particles larger than 50 µm Fig. (2.4) (2) some damage has usually occurred when the magnetic plug picks up debris large enough for observation.

It has been found that for the particle range of 10 µm to 50 µm, Ferrography can be effectively applied. Hence it bridges the gap between SOAP and magnetic plug applications. This is evident from the Figure (2.4). (2) Besides this, Ferrography has many major advantages over SOAP and magnetic plugs.

(i) Ferrography not only gives a quantitative measure of the wear but also enables to get the wear particles deposited on a microscope substrate for further analysis. The size, shape and density of the wear particles can give a clear picture about the condition of the system.

(ii) The Direct Reading Ferrograph gives readings for large particles (larger than 5 µm) and small particles [less than 5 µm] separately. The magnetic separation is nearly 100% .

It can be seen from Figure (2.5) that as wear process progresses from normal condition to failure the particle size and concentration go on increasing. All abnormal wear modes result in increased levels of wear particle concentration and most failure modes result in

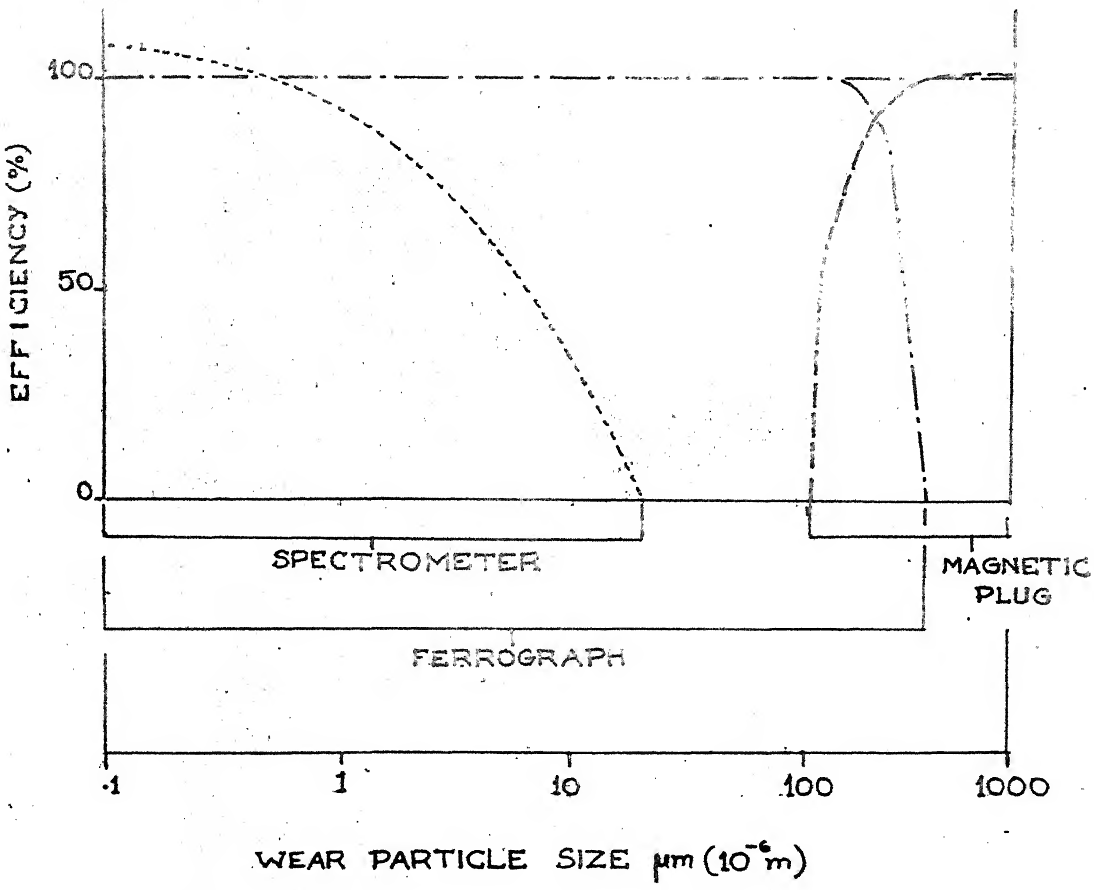

Fig. 2.4 Particle Size vs Measurement Efficiency of Three Wear Monitoring Instruments'

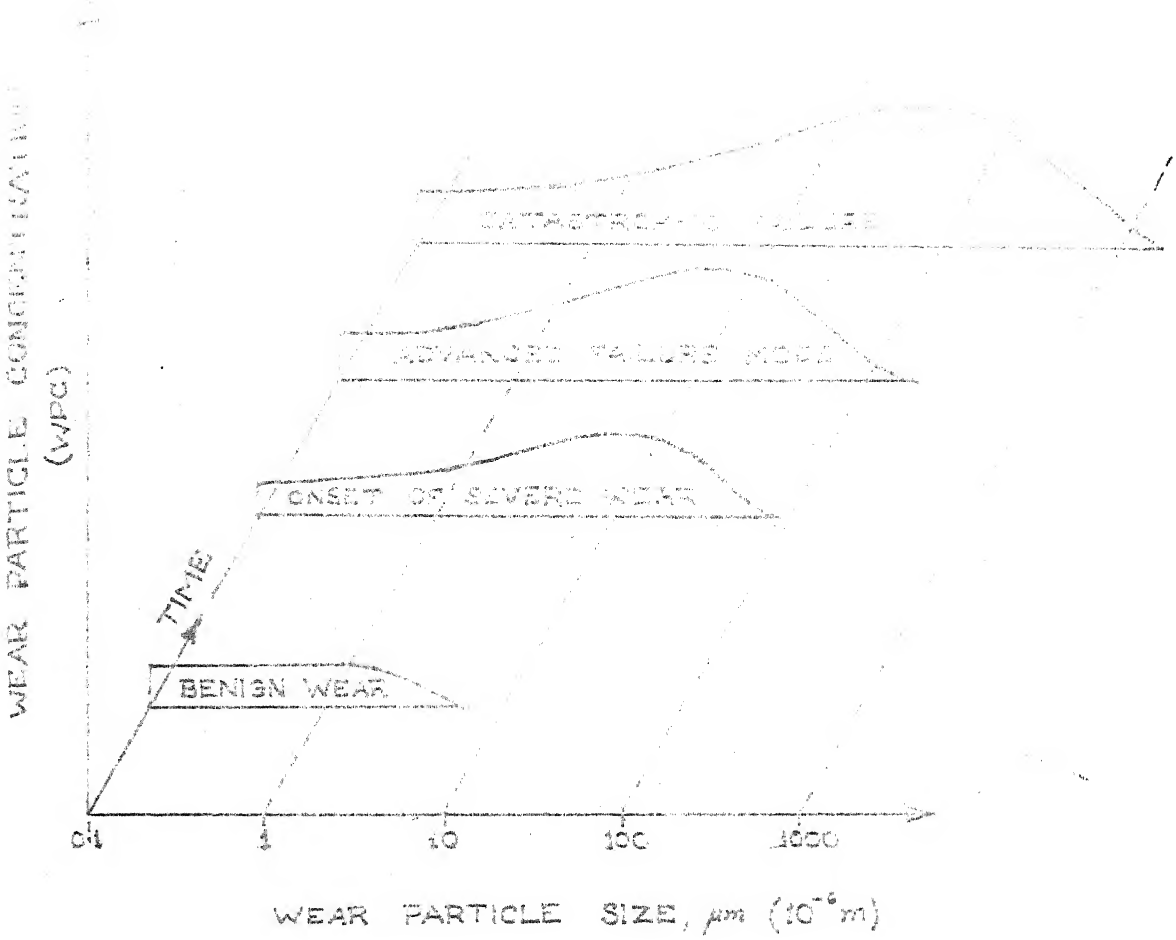

Fig. 2.5 Typical Progression of Severe Wear

a trend toward larger particles.

So , from a DR Ferrograph, one can find out the onset of most failure modes. The ferrograph in general covers the particle size range where the onset of most failure modes is likely to occur i.e. 15 to 200 μm Fig.(2.5). This is not possible in SOAP.

(iii) By applying techniques like temper colour identifications, bichromatic light with filters and polirizers, particles can be identified and can be traced back to the machinery components thus indicating which part of the machine is facing the danger of failure.

(iv) Non-magnetic metallic and non-metallic particles can also be deposited separately for the analysis. Thus information regarding failure of rubber seals etc. can be obtained.

All these aspects make this technique a very effective tool for condition monitoring.

2.3 The Duplex Ferrograph Analyzer:

The present studies were conducted on "Duplex Ferrogram Analyzer" Model No. 7069-4-220, manufactured by Foxboro Company. (6,7)

This model has the following units:

(i) Direct Reading (DR) Ferrograph.

(ii) Analytical Ferrograph.

(iii) The Ferroscope and its controller unit.

The top and the front views of the Analyzer are shown in Figures II-1 and II-2. The front views of the ferroscope and the controller are shown in Figures II-3 and II-4 respectively.

The DR Ferrograph and the Analytical Ferrograph are housed in a single unit and have a common ON/OFF switch. The Ferroscope is a separate unit with the microscope connected to the controller. The microscope has a polaroid camera as an accessory. The ferroscope controller has a Ferrogram reader in it.

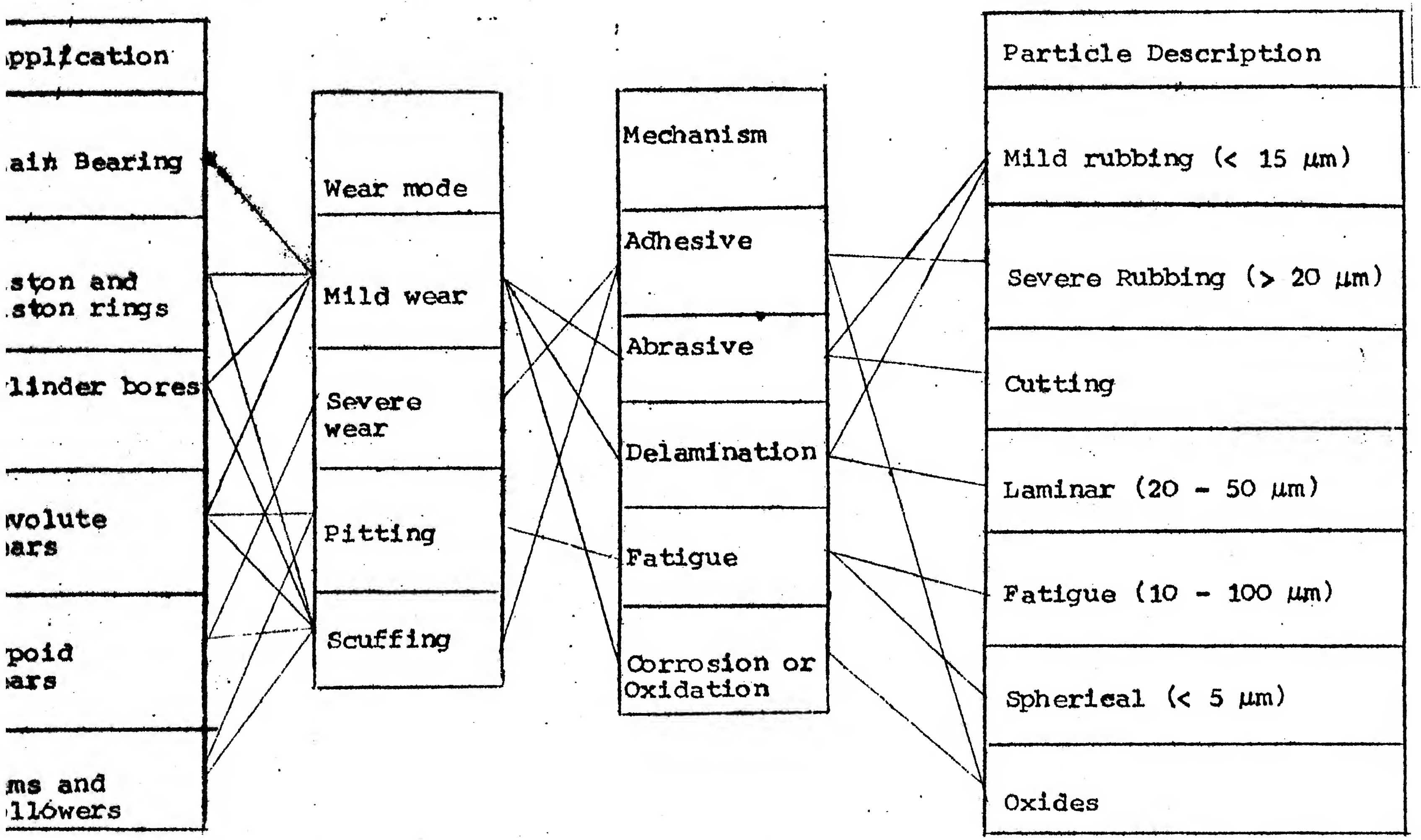

Fig. 3.1 Relationships between particle description and wear behavior

3.1.1 Diesel Engine:

From Fig. (3.1) it can be seen that the main modes of wear are scuffing and mild wear which may be due to abrasive wear adhesive wear corrosion or oxidation wear. The particles generated are mild rubbing, severe rubbing, cutting, laminar, spherical and the oxide types. Hence the engine lubricating oil would contain wear particles of these types.

The lubricating system for a diesel engine is shown in Figure (3.2). It uses pressure feed to all the important bearings. The big ends of the connecting rod are pressure fed by the passages drilled in the crank shaft. The piston pins and the cylinder walls are splash lubricated by the oil thrown up by the ends of pressure lubricated big ends. The gears, camshafts, valves etc. are normally lubricated by the oil pumped upto the top of the engine and allowed to run down again to the sump by gravity, or in some cases they may be pressure lubricated by drilled passages. The oil is supplied by a direct driven gear pump from an oil reservoir situated at the bottom of the crank case. The oil is fed to a pressure gallery from which the main bearings are fed by individual leads. A relief valve leads the excess oil back to the sump. The oil filter is situated between the sump and the cylinder assembly.

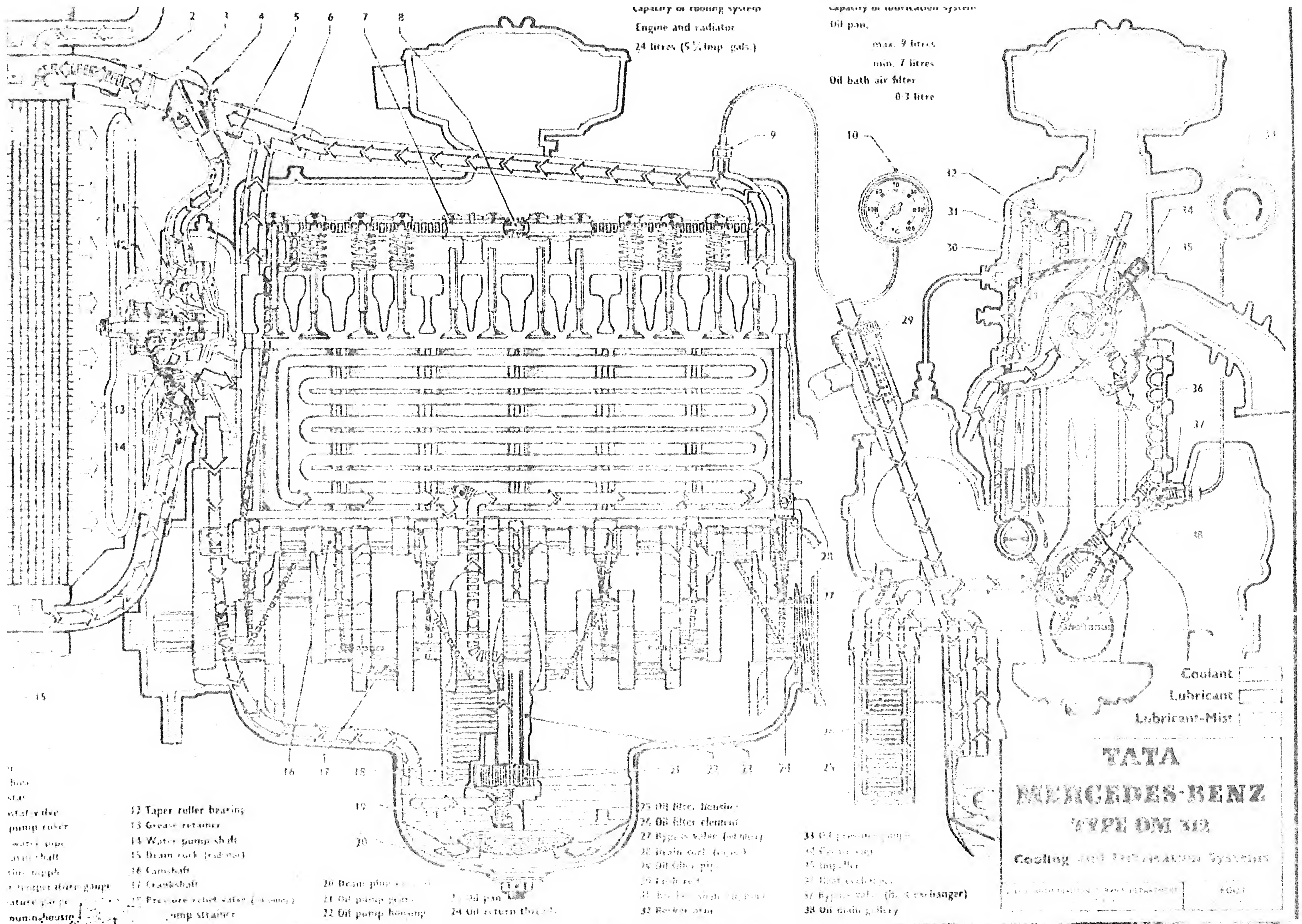
Capacity of cooling system
Engine and radiator
24 litres (5½ Imp. gals.)
Capacity of lubrication system
Oil pan,
max. 9 litres
min. 7 litres
Oil bath air filter
0·3 litre
Coolant
Lubricant
Lubricant-Mist
TATA
MERCEDES-BENZ
TYPE OM 312
Cooling and Lubrication Systems
12 Taper roller bearing
13 Grease retainer
14 Water pump shaft
15 Drain cock (radiator)
16 Camshaft
17 Crankshaft
pump strainer
20 Drain plug
21 Oil pump gears
22 Oil pump housing
24 Oil return throttle
25 Oil filter housing
26 Oil filter element
27 Bypass valve (oil filter)
29 Oil filler pipe
32 Rocker arm
33 Oil pressure gauge
37 Bypass valve (heat exchanger)
38 Oil drain gallery

Fig. 44

The oil from the filter circulates around the cooling water jacket and then goes to crank shaft bearings and to other parts. By this, the oil is cooled during every pass. In a diesel engine, the oil passes through all the parts that are to be lubricated and hence contains the wear particles generated by any of the above mentioned parts.

The various metal particles found in the oil are of different materials depending upon their source of generation. Table (3.1) gives the details of the materials of the various engine parts.(9)

Table 3.1

Component	Wear particle material
Piston rings	Cast iron, Cr ; Mo ; Cu
Piston	Al, Si alloy, Sn or Pb coating
Cylinder liner	Cast iron, Cr.
Crank shaft	Low carbon alloy steel
Main bearings, big end bearings and small end bearings	Pb-Sn, Cu-Pb-Sn ; Al-Si, Al-Sn ; Cd
Thrust bearings	Phosphor bronze ; Al-Sn ; Cu-Pb
Cam shaft	Cast iron
Valve train	High alloy steel ; Ni
Auxilliary drive	Phosphor bronze, low carbon alloy steel

3.1.2 Gear Box:

From Fig. (3.1) it is seen that the main modes of wear for the involute gears are mild wear, pitting and scuffing. The wear mechanisms that cause these failures are abrasive wear, fatigue, adhesion and corrosion. The particles that can be found in the gear box oil are mild rubbing particles, severe rubbing particles, cutting particles, fatigue and spherical particles. Oxide particles are also present. The operating regimes of a gear system are shown in Fig. (3.3) [10].

The gear box lubrication is of splash type. The gear teeth act as their own pumps to throw oil into the contact areas. This action will maintain a constant wedge in front of the meshing areas. The heat generated at the contact surfaces is dissipated into the oil itself.

3.3 Experimental Procedure:

3.3.1 Oil Sample Collection:

The oil sample in all the three cases was collected from the oil sump by loosening the drain plug. The oil was collected after the system had run atleast for 15 minutes before the sampling. Each time, approximately 50 ml of the sample was collected. Thus

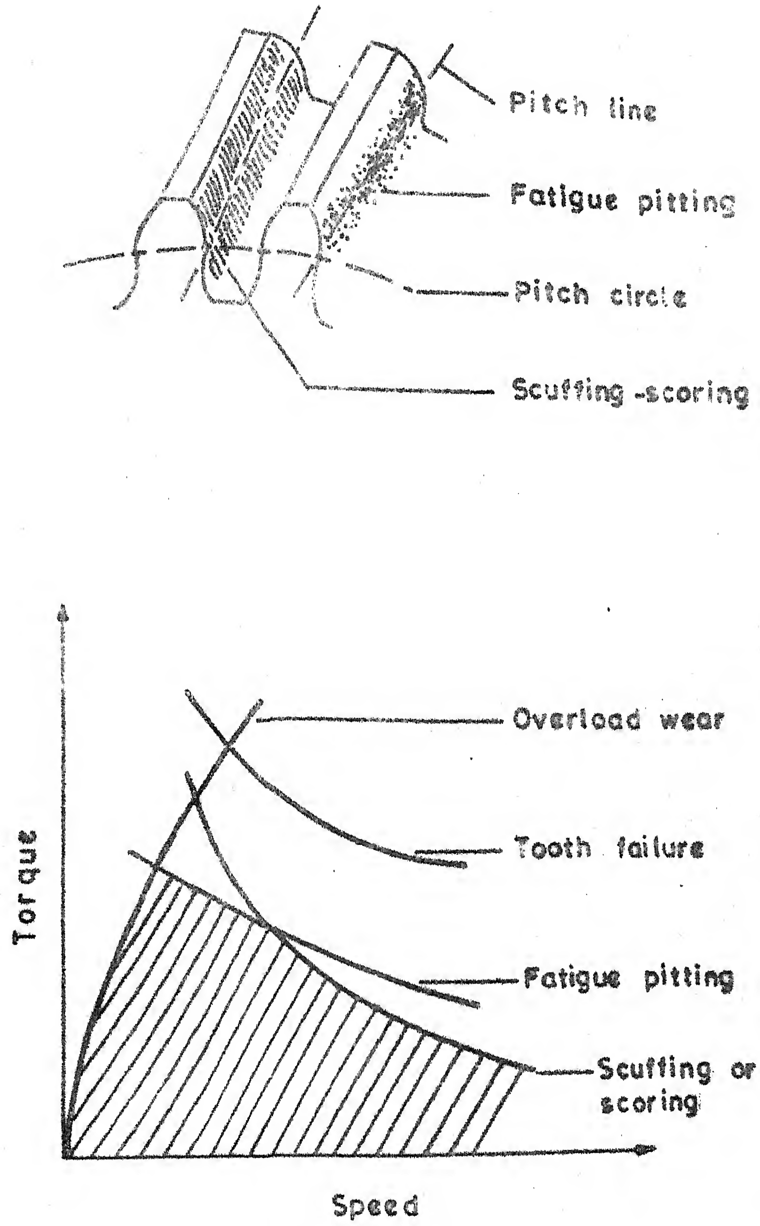

Fig. 3.3 Gear failure modes and operating regimes.

the sampling was maintained uniform throughout the analysis. For the bus engine the sample was collected for every 1000 km of running of the bus and for the gear box for every 2000 km of running. For the new scooter gear box, the oil was collected every time it was changed as per the manufacturer's instructions (i.e. after 450 km, 1250 km and 2250 km).

3.3.2 Oil Sample Analysis:

Before the oil was run in the Ferrograph analyzer, it was diluted to get the readings in the linear range of the instrument. The dilution also gives a better deposition on the ferrogram. For the engine oil, the dilution ratio was 1:3 [oil to mixture of oil and diluent] in most of the cases. For the bus gear box oil, a dilution of 1:1000 had to be used. And for the scooter gear box oil, it was 1:10. In the case of bus gear box oil, the oil sample was first diluted in 100 ml of fresh oil of the same grade. This mixture was again diluted to 1:10, giving an overall dilution of 1:1000.

The diluted oil was first run in the DR Ferrograph. The details of the procedure are given in Appendix II and the readings D_L and D_S were noted and are recorded in Table (4.1 , 4.4 and 4.6).

Then a ferrogram was prepared for each sample, the procedure for which is also given in Appendix II.

The ferrogram was then studied under the microscope. Readings for the ferrogram were taken by the help of Ferrogram Reader. The procedure followed for taking the readings by the Ferrogram Reader is as follows.

(i) The Ferrogram Reader was initially adjusted to zero.

(ii) With a magnification of 100, the reading was taken at the entry deposit. The reading was taken at the entry deposit. This reading is defined as R_L.

(iii) Then the reading was taken at a position 5 mm from the entry and was recorded as R_S.

(iv) Then the readings at 10 mm, 20 mm etc. upto 50 mm from the exit end, were taken.

All the readings were taken 3 times to reduce the error. The mean of the three readings was recorded (Table 4.2 and 4.5).

The ferrogram was observed under the microscope in order to assess the mode of wear and the part that contributed for the wear. Red and green filters and polarizers were used. Wherever, it was essential the temper color test was conducted to identify the material. Table (3.2) gives the details of this test.[9]

Table 3.2

Temper colour Test

Materials	Temper colour			
	330°C	400°C	480°C	540°C
Carbon steels and low alloy steels	Blue	Light grey	-	-
Medium alloy steels approx. 3-8% alloy	Straw to Bronze	Deep bronze with mottled bluing	-	-
High Nickel alloy	no change	No change	Bronze with significant bluing	All particle blue or blue grey
High alloy steel	No change	Generally no change Yellowing on some particles	Straw to bronze with slight bluing	Straw to bronze some showing mottled blue.

CHAPTER - IV

RESULTS AND DISCUSSIONS

The large particle readings (D_L) and the small particle readings (D_S) are tabulated against distance run by the vehicles. These readings are normalized to make them consistent as regards the volume of oil used. The normalized readings 'nD_L' and 'nD_S' are then used for further calculations. These readings and calculations are recorded in Table 4.1, 4.4 and 4.6 for the diesel engine,bus gear box and scooter gear box respectively.

The 'Ferrogram Reader' readings (R_L) and (R_S) at the entry and at a distance of 5 mm downstream from the entry position are tabulated against distance run by the engine. These are recorded in Table 4.3 for diesel engine and in Table 4.5 for the bus gear box.

In Table 4.2, the 'Ferrogram Reader' readings at positions 10 mm, 20 mm etc. from the exit end of the ferrogram are recorded as R_{10} , R_{20} , R_{30} etc. These readings are for the diesel engine. The 'Area under the curve' is also tabulated in Table 4.2.

The readings and calculations in Tables 4.1, 4.2, 4.4 and 4.6 are for a sample volume of 1 ml. But in Tables 4.3 and 4.5 they are calculated for a sample volume of 3 ml. The AUC values throughout are for 1 ml of sample volume.

The details of calculations for a specimen reading are shown in Appendix III.

4.1 Diesel Engine Wear:

Ten oil samples were collected during this study. Oil was changed three times in this period. The Figures 4.1 to 4.5 show the variation of the wear parameters as functions of distance covered by the bus.

The engine wear shows a peak value at the start of the study. The SWI and WI values are high both in DR analysis as well as Ferrogram analysis. The AUC reading is also high which indicates that the oil sample contained a high concentration of wear particles. By observing the ferrogram under the microscope, it was found that the oil had a significant quantity of coagulated particles. Large chunks of ferrous particles were clustered together in the entry deposit. Ferrous oxide chunks were also found in large number. These appear as red chunks. They are somewhat spherical in shape (i.e. height to breadth ratio is high). Some burnt

oxides and metal particles were also observed along with fibrous non-metallic debris. The oil was obviously very much contaminated. The presence of dark brown particles indicated that the lubricating oil supply was not sufficient. Later it was learnt from the Transport Section that the oil change was over due. The dipstick test showed an oil loss of about 3 litres. Three litres of oil was added to the system. The unusually high values could be due to the fact that the oil was tapped from the cold engine. The particles settling at the bottom of the sump were found in abundance in the oil sample. For the subsequent readings, oil was tapped when the engine was hot.

The oil was changed after the second reading was taken. The sample No. 2 was taken from the oil that was removed. The wear index for this sample was also high. Ferrogram observation showed big rod like metal particles aligned along the magnetic field near the entry. A few Cu particles were also seen, which were laminar indicating that mild wear was in progress. Small chunks of metallic particles were observed which showed that fatigue was under way in one of the components. But since these particles were small, the magnitude of this wear was not considered to be high. It is to be noted that copper particles could belong to the journal bearings.

After the oil change, the curves reach the lowest valley. This was expected as the new oil had very less concentration of particles. The particles size at the entry was also small (10 μm).

Then the curves remain almost parallel to the X axis for a considerable amount of engine running. (3165 to 11069 kms). During this period, the engine wear was normal. The ferroscope analysis also confirmed this. These particles were small, uniform in size and no abnormal particles were seen.

Thereafter the wear curves shoot up giving very high indices at 11,704 km. reading (9738 km after the previous oil change). The AUC curve also shoots up at this point which means that the debris concentration is very high. The ferrogram analysis was in conformity with this. The ferrogram for this oil sample was fully covered by metallic as well as non-metallic debris. It was found that the deposit contained many fibre like particles which appeared bright in polarized light. These particles were of organic material like cotton, fibres, plastic threads etc. and could have come from filter, seals, dust etc. A new filter was fitted along the oil change. At this stage the bus was assigned duty outside Kanpur for a period of 20-25 days. The oil analysis after the return of the bus

showed high contamination in the oil. The oil was changed at 20568 km. After the change the oil was tested for a'distance covered'reading of 21699 kms. The wear indices were high inspite of the oil change. A thorough analysis of the ferrogram was done. The deposition was dense. The particles were large (> 100μm) and of various shapes. At the entry, large and thick chunks were observed which appeared red when red filter was used. They were magnetic particles since they alligned along the magnetic field. Many oxide particles were also seen over the magnetic particles. All along the ferrogram while lustrous particles with flake like appearance were seen. These particles were found to be non-magnetic. They could be chromium or alluminium, since the shape of these particles indicated severe abrasive wear, the particles originated from piston rings or cylinder linings where chromium can be found. Some copper particles of spherical shape were seen which indicated the wear in the main bearing, big end and small end bearing.

In order to identify the material at the entry temper color test was conducted. The temper color test showed the presence of low alloy steel particles at the entry. These particles are tempered blue after heating the ferrogram to 330°C. Traces of straw and bronze

color was also found on some particles. Comparison with previous workers' report [12] indicates that these are cast iron particles and could have originated from piston rings, camshaft or cylinder. A detailed report for this sample was prepared which could form the guide for diagonses of the wear in engine parts.

The study detailed in this section indicated that the wear of piston rings, cylinder liner , bearings and other parts is shown up in the lubricating oil and the'Severity of Wear Index' and 'Wear Index' help to suggest the oil change for avoiding accelerated wear.

4.2 Bus Gear Box Wear:

The readings and calculations done on the DR Ferrograph are shown in Table 4.4 and the Ferrogram Readings and calculations for the bus gear box are shown in Table 4.5 and Figures 4.6 to 4.11. Fig. (4.6) shows that D_L and D_S values for the gear box increase gradually. Hence the total wear $n(D_L + D_S)$ and the severity of wear $n(D_L - D_S)$ increase steadily. In the gear box, the wear particle production under normal wear conditions goes on increasing at a steady rate. The large particle production rate is steady and the small particles are produced due to 'mild wear' as well as by the breaking down of the large particles into

small fragments. Since there is no filter in the system, the concentration of the particles goes on increasing. This increase is steady under normal conditions. But, when there is an onset of severe wear, the large particle concentration increases abruptly. In the present case it was found that the wear in the gear box was normal.

The 'Wear Index' and the 'Severity of Wear Index' curves also show a gradual increase. Thus there was no cause for alarm. In Fig. (4.7), the values of nR_L and nR_S obtained from the ferrograms were found to increase at a higher rate as compared to the nD_L and nD_S readings. This means that the contamination due to particles other than wear was increasing at a faster rate. In a ferrogram, reading obtained is the percentage area covered by the debris, both due to wear analysis as well as due to contamination from other sources like metal oxides, burnt products of organic material and chemical products formed by the action of addition in the oil. These particles were found to be on the increase. The observation of the ferrogram was done. A uniform distribution of organic particles which showed no regular alignment along the magnetic field, nor the size selectivity, was found to exist all along the ferrograms. However, the metal particles were of uniform

size and shape and the deposition pattern was in an ordered fashion with respect to field alignment and size.

The temper colour test was conducted for one of the ferrograms. After heating the ferrogram upto 400°C and observing under the microscope, the wear particles exhibited a straw to deep bronze color indicating that the material was cast iron or medium alloy steel. Since the gears are made of these materials, the particles were generated from the gear teeth.

One or two particles of abnormal size and shape were found. The major dimension measured 60 µm. It exhibited deep bronze and traces of red color. The red color showed that oxidation wear was taking place in the system. It indicated that the gear oil had lost its lubricating characteristics and need to be changed. The suggestion was passed on to the Transport Section.

4.3 Scooter Gear Box Wear:

Figs. (4.12) and (4.13) show the curves for this gear box. Since the scooter was a new one, the wear process is theoretically taken to be zero at zero kilimeters of running. So all the curves start from the origin. Since the actual oil test was not done until after the first oil change at 450 kms of running, this portion of the curves are shown as dotted.

The D_L and D_S values were very high at 450km. Then there was a gradual decrease in the readings.This was expected because, the gear box was in the " running-in" condition during that period. The third set of readings was the lowest of all the three. SWI, WI and PLP curves reached a maximum at 1250 km readings. This indicated that the wear was severe at that stage. But when the scooter had covered 2500 kms, these values were seen to be lower. So it was concluded that the gear box system has " run-in".

4.4 Comparison Between DR Readings and Ferrogram Readings:

The figure 4.14 shows the comparison between the DR readings and the Ferrogram readings for different oil samples. The two curves are for the large particle readings and the small particle readings. It is found that the DR readings are higher than the Ferrogram readings. However, the readings read out depend upon the characteristics and geometry of the sensors.

TABLE 4.1

DR. Ferrograph Readings for Diesel Engine

Sample No.	Odometer Readings (kms)	Vehicle Running (km)	Dilution 'n'	D_L	D_S	nD_L	nD_S	Total wear	Severity of wear	WI (10^3)	SWI (10^3)	PLP %
1	59820	0	11	52.5	28.5	577.5	313.5	891.0	264.0	235.22	152.46	84.21
2	*60918	1098	3	81.8	27.5	245.4	82.5	327.9	162.9	53.42	39.98	49.70
3	61786	1966	3	37.5	17.7	112.5	53.1	165.6	59.4	9.84	6.68	35.87
4	62985	3165	3	52.1	15.9	156.3	47.7	204.0	108.6	22.15	16.97	53.23
5	65486	5666	3	56.2	24.6	168.6	73.8	242.4	94.8	23.98	15.98	39.11
6	69194	9374	3	138.5	56.5	415.5	169.5	585.0	246.0	143.91	102.21	42.05
7	70889	11069	3	62.8	27.9	188.4	83.7	272.1	104.7	28.49	19.73	38.48
8	*71524	11704	3	100.1	30.8	300.3	92.4	392.7	207.9	81.64	62.43	71.06
9	78660	18840	4	97.8	39.9	391.2	159.6	550.8	231.6	127.57	90.60	42.05
10	81519	21699	4	111.6	36.4	446.4	145.6	444.0	300.8	178.07	134.28	53.79

* The oil was changed after this reading.

TABLE 4.2

'Area under the curve' for Diesel Engine

Sample No.	Ferrogram	Odometer Reading (km)	Vehicle Running (km)	Dilution	Readings recorded by Ferrogram Reader at various locations on the Ferrogram R_{10}	R_{20}	R_{30}	R_{40}	R_{50}	R_L	R_S
1	2	3	4	5	6	7	8	9	10	11	12
2	B	60918	1098	3	31.90	24.70	21.73	25.60	18.50	29.60	15.63
3	C	*61786	1966	3	23.40	12.20	12.63	15.63	13.70	16.77	10.67
4	D	62985	3165	3	16.30	19.50	23.40	15.10	16.23	24.90	14.27
5	E	65486	5666	3	17.20	18.23	22.60	20.40	17.33	25.98	14.46
6	F	69194	9374	-	70.83	76.60	70.17	37.40	40.93	81.36	38.80
7	G	70389	11069	3	27.83	24.90	32.43	25.97	20.60	43.43	21.25
8	H	*71524	117C4	2	37.50	30.50	28.72	26.66	34.33	77.32	44.40
9	I	78660	18840	3	29.73	44.90	44.93	26.00	30.00	75.13	56.30
10	J	81519	21699	3	40.17	60.60	48.67	43.33	48.67	74.43	48.70

Area under the curve for various segments (γ mm/ml) A_1	A_2	A_3	A_4	A_5	AUC (γ mm/ml)
13	14	15	16	17	18
283.00	232.15	236.60	220.50	232.40	1204.65
178.00	124.15	141.30	146.65	121.88	711.98
179.00	214.50	192.50	156.70	164.52	907.22
177.15	204.20	215.00	188.70	173.28	958.33
736.15	133.85	537.85	391.65	489.16	762.89
263.65	286.50	292.00	232.85	256.12	1331.12
340.00	296.10	276.90	305.00	446.56	1664.56
373.15	449.15	354.65	280.00	480.52	1937.47
503.85	546.35	460.00	460.00	492.40	2462.60

* The oil was changed after this reading.

TABLE 4.3

Ferrogram Readings for Diesel Engine

Sample No.	Ferrogram	Odometer Readings (km)	Vehicle Running (km)	Dilution	R_L	R_S	nR_L	nR_S
1	2	3	4	5	6	7	8	9
1	A	59820	0	11	13.50	4.50	148.50	49.50
2	B	*60918	1098	3	39.6	15.63	118.80	46.89
3	C	61786	1966	3	16.77	10.67	50.31	32.01
4	D	62985	3165	3	24.90	14.30	74.70	42.90
5	E	65486	5666	3	25.98	14.46	77.90	43.40
6	F	69194	9374	-	81.37	38.80	81.37	38.80
7	G	70889	11069	3	43.43	21.17	130.30	63.50
8	H	*71524	11704	2	77.32	44.40	154.65	88.80
9	I	78669	18840	3	75.13	56.30	225.40	168.90
10	J	81519	21699	3	74.43	48.70	223.29	141.60

Total wear	Severity of wear	WI(10^3)	SWI(10^3)	PLP %
10	11	12	13	14
198.00	99.00	19.60	14.70	50.00
165.69	71.91	11.91	8.54	43.40
82.32	13.30	1.51	0.92	22.23
117.60	31.80	3.74	2.38	27.04
121.32	34.52	4.19	2.70	28.45
120.17	42.57	5.12	3.47	35.42
193.80	66.80	12.95	8.70	34.47
243.45	65.85	16.03	10.21	27.05
294.30	56.50	22.26	12.71	14.33
269.40	77.20	28.52	17.24	20.90

* The oil was changed after this reading.

TABLE 4.4

DR. Ferrograph Readings for Bus Gear box

Sample No.	Odometer Readings (kms)	Vehicle Running (km)	Dilution 'n'	D_L	D_S	nD_L (10^3)	nD_S (10^3)	Total wear (10^3)	Severity of wear (10^3)	WI (10^8)	SWI (10^8)	PLP %
1	46796	0	500	121.5	45.8	60.75	22.90	83.65	37.85	31.66	22.99	45.25
2	49640	2844	1000	72.5	27.5	72.50	27.50	100.00	45.00	45.00	32.62	45.00
3	52087	5291	1000	75.2	26.7	75.20	26.70	101.90	48.50	49.42	36.47	47.60

TABLE 4.5

Ferrogram Readings for Bus Gear Box

Sample No.	Ferrogram No.	Odometer Readings (kms)	Vehicle Running (km)	Dilution 'n'	Readings at various locations on the Ferrogram R_{10}	R_{20}	R_{30}	R_{40}	R_{50}	R_L	R_S	AUC (10^4 γmm/ml)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	17	46797	0	500	42.27	43.67	44.4	74.4	35.8	39.9	13.0	39.89
2	18	49640	2844	1000	24.67	14.93	18.2	23.23	32.0	41.6		36.6
3	19	52087	5291	1000	53.50	29.00	24.9	0.55	26.0	55.00		50.0

nR_L (10^3)	nR_S (10^3)	Total wear (10^3)	Severity of wear (10^3)	WI (10^8)	SWI (10^8)	PLP %
14	15	16	17	18	19	20
19.95	9.0	28.95	10.95	3.17	2.18	37.82
41.60	36.6	78.20	5.00	3.91	2.08	6.40
55.00	50.0	105.0	5.00	5.25	2.75	4.76

TABLE 4.6

DR. Ferrograph Readings for Scooter Gear Box

Sample No.	Odometer Readings (kms)	Vehicle Running (km)	Dilution 'n'	D_L	D_S	nD_L	nD_S	Total wear	Severity of wear	WI (10^4)	SWI (10^4)	PLP %
1.	450	0	10	185.9	162.3	1859	1623	3482	236	32.18	43.87	6.78
2.	1250	800	10	139.5	57.8	1395	578	1973	817	161.19	113.97	58.56
3.	2500	2050	10	96.6	62.5	966	625	1591	331	54.25	32.94	21.43

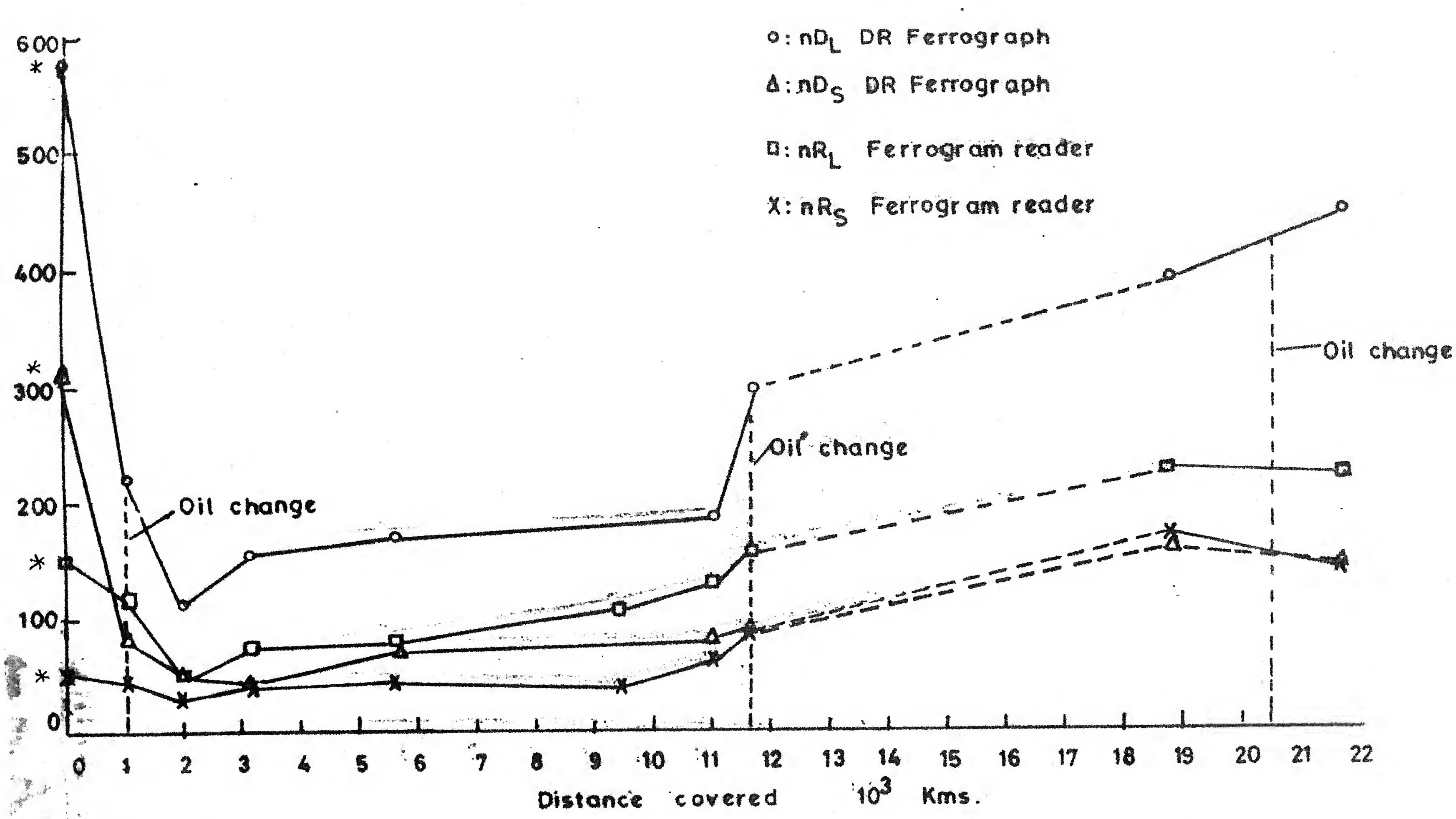

Fig.4.1 Variation of normalised large and small particle readings (Diesel engine).

(* - large values due to ~~poor~~ settling of particles. refer page 38)

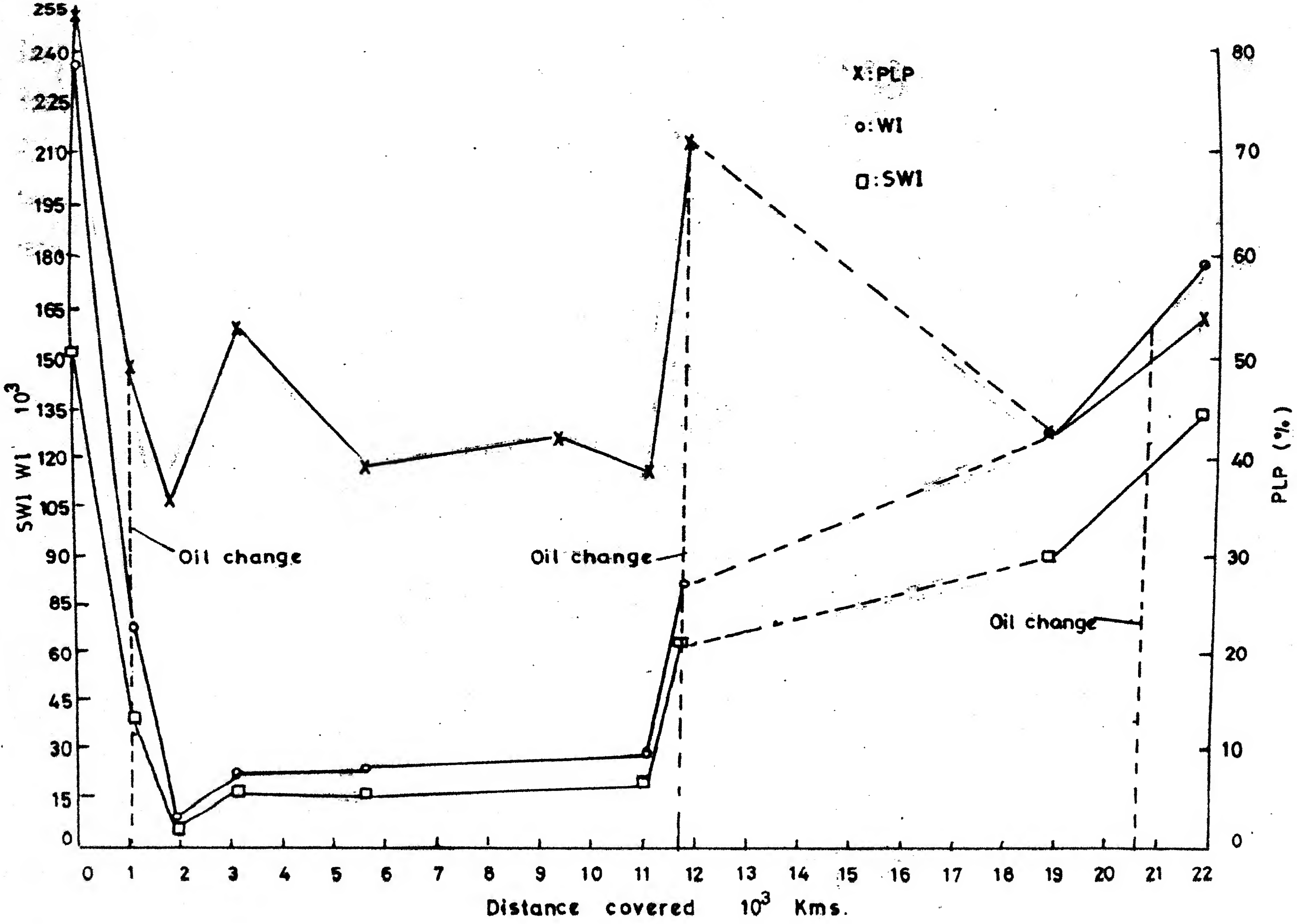

Fig. 4.3 WI, SWI and PLP from Ferrograph (Diesel engine).

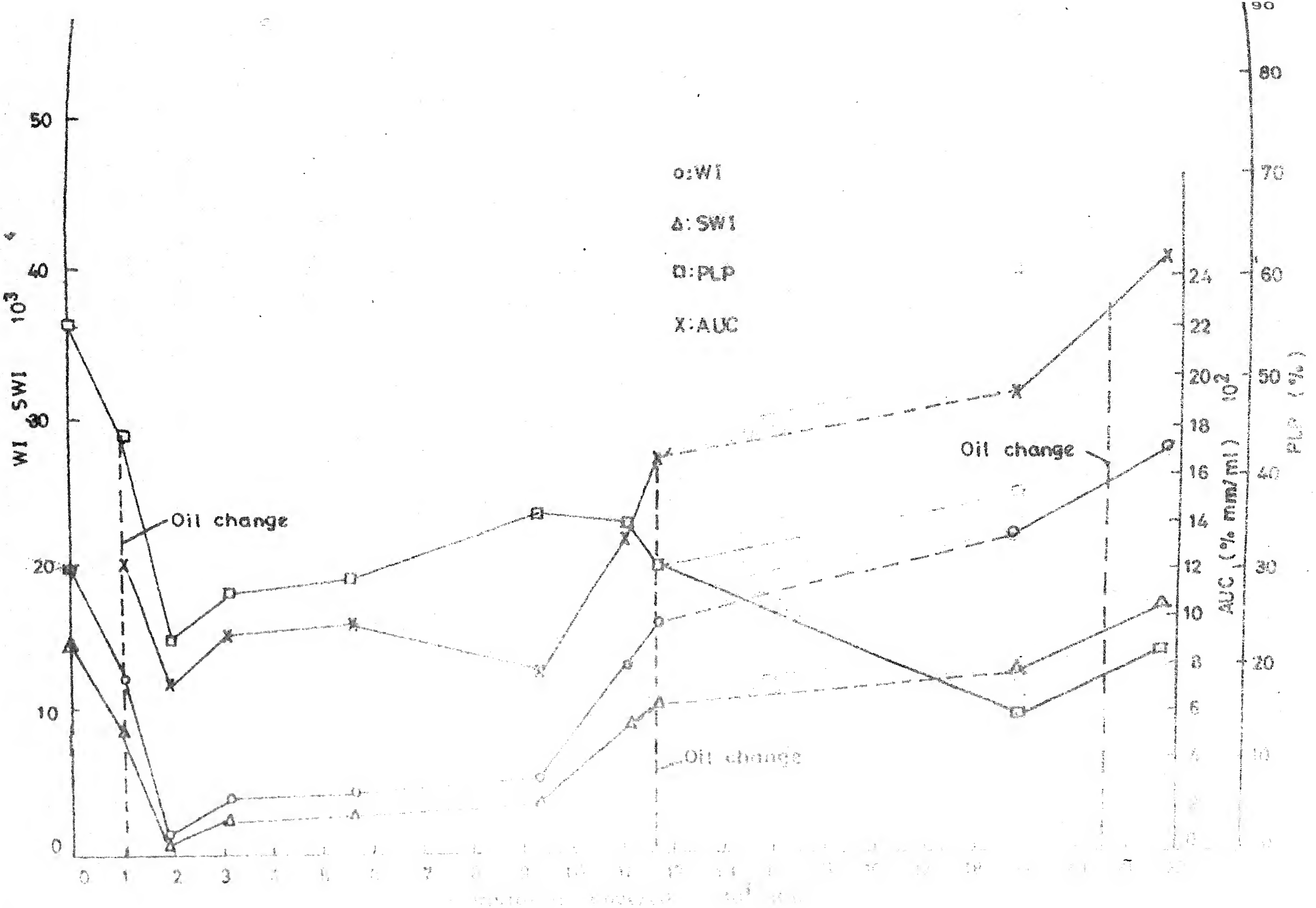
WI SWI 10^3
o:WI
Δ:SWI
□:PLP
X:AUC
Oil change
Oil change
Oil change
AUC (% mm/ml) 10^2
PLP (%)
0
10
20
30
40
50
0
1
2
3
6
8
10
12
14
16
18
20
22
24
20
30
40
50
60
70
80

Fig. [illegible] WI, SWI, [illegible]

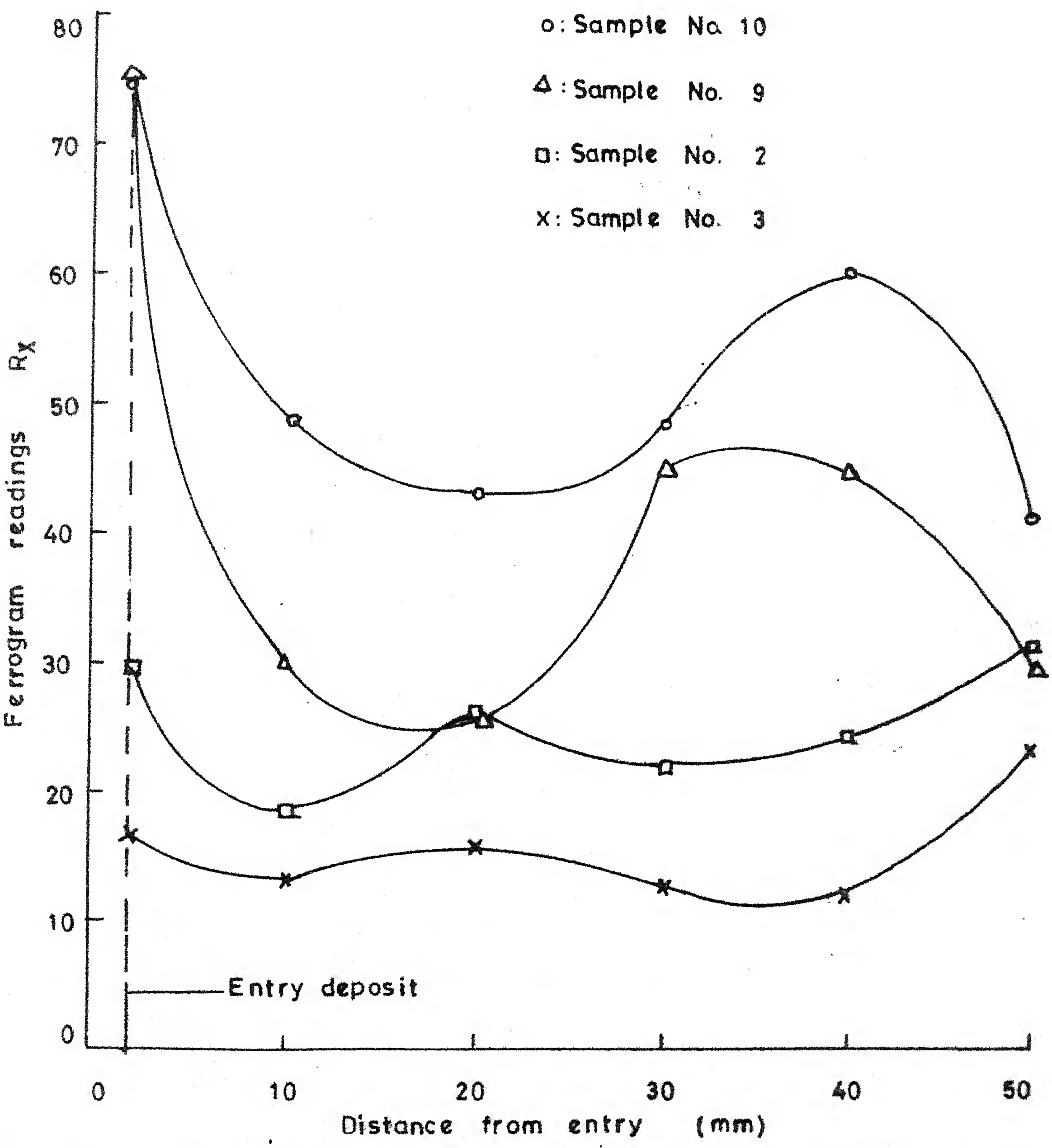

Fig. 4.5 Ferrogram readings along the ferrogram for diesel engine.

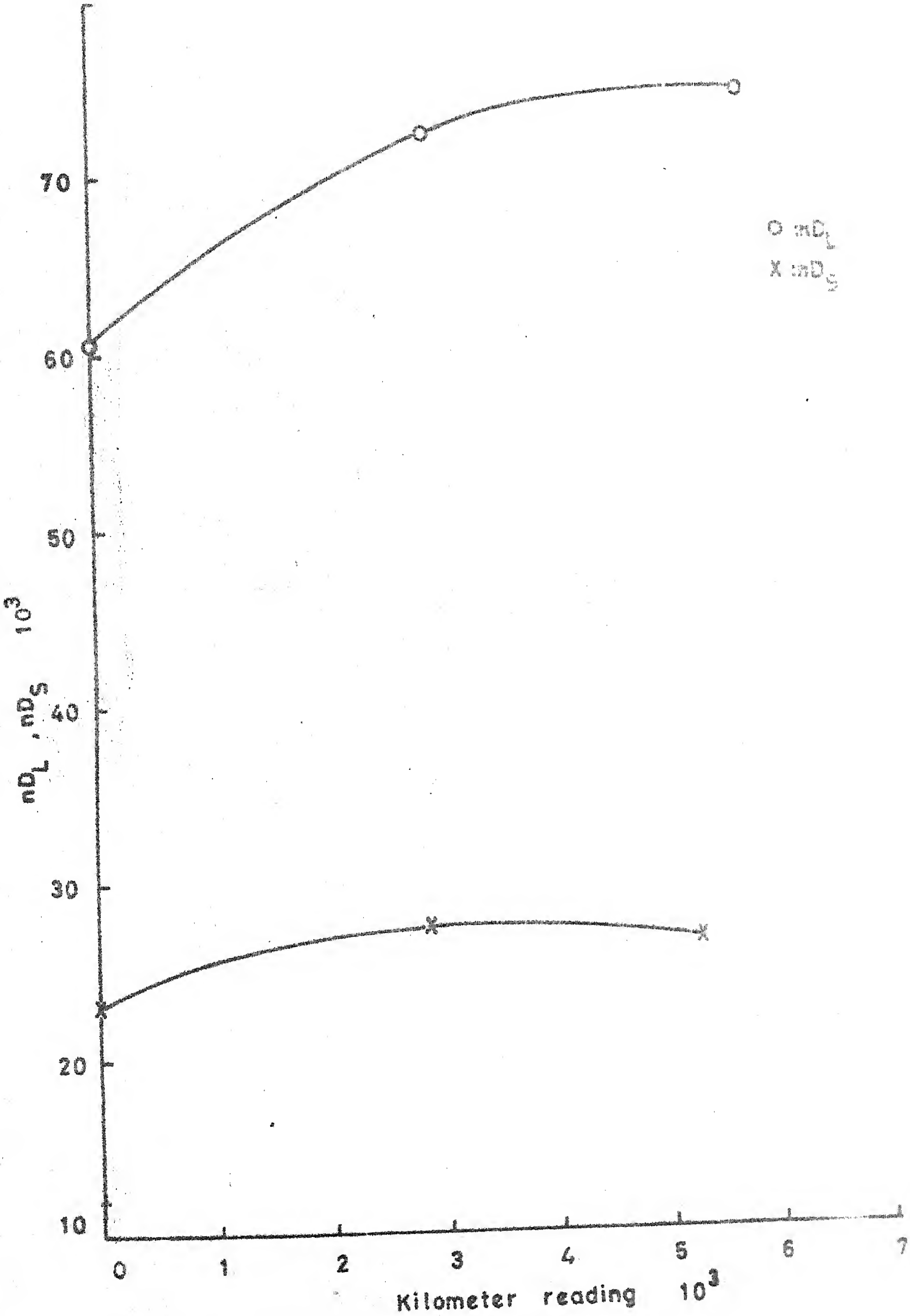

Fig. 4.6 Variation of D_L and D_S with distance run.
(Bus gear box).

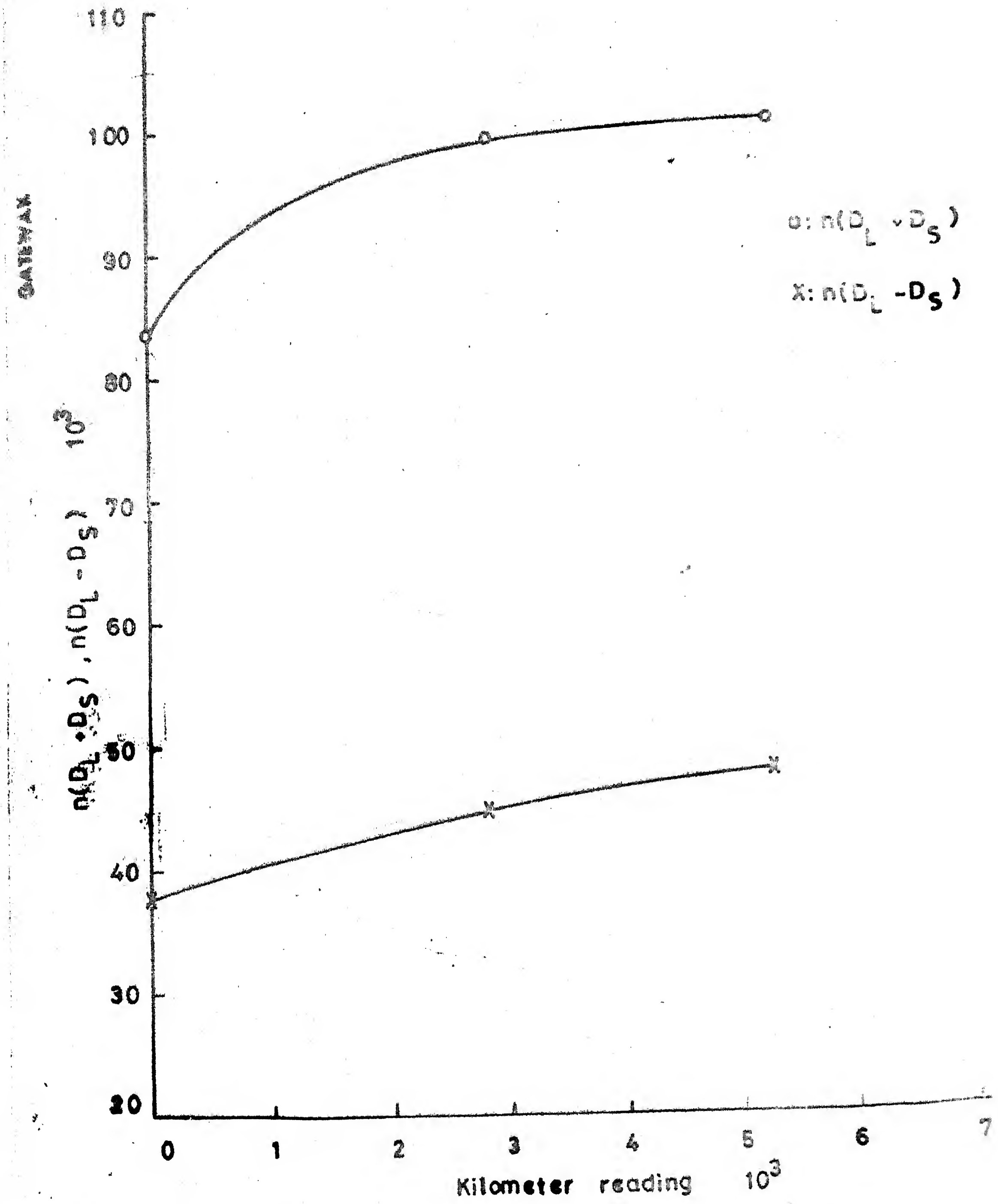

Fig. 4.7 Total wear and severity of wear vs distance covered (Bus gear box).

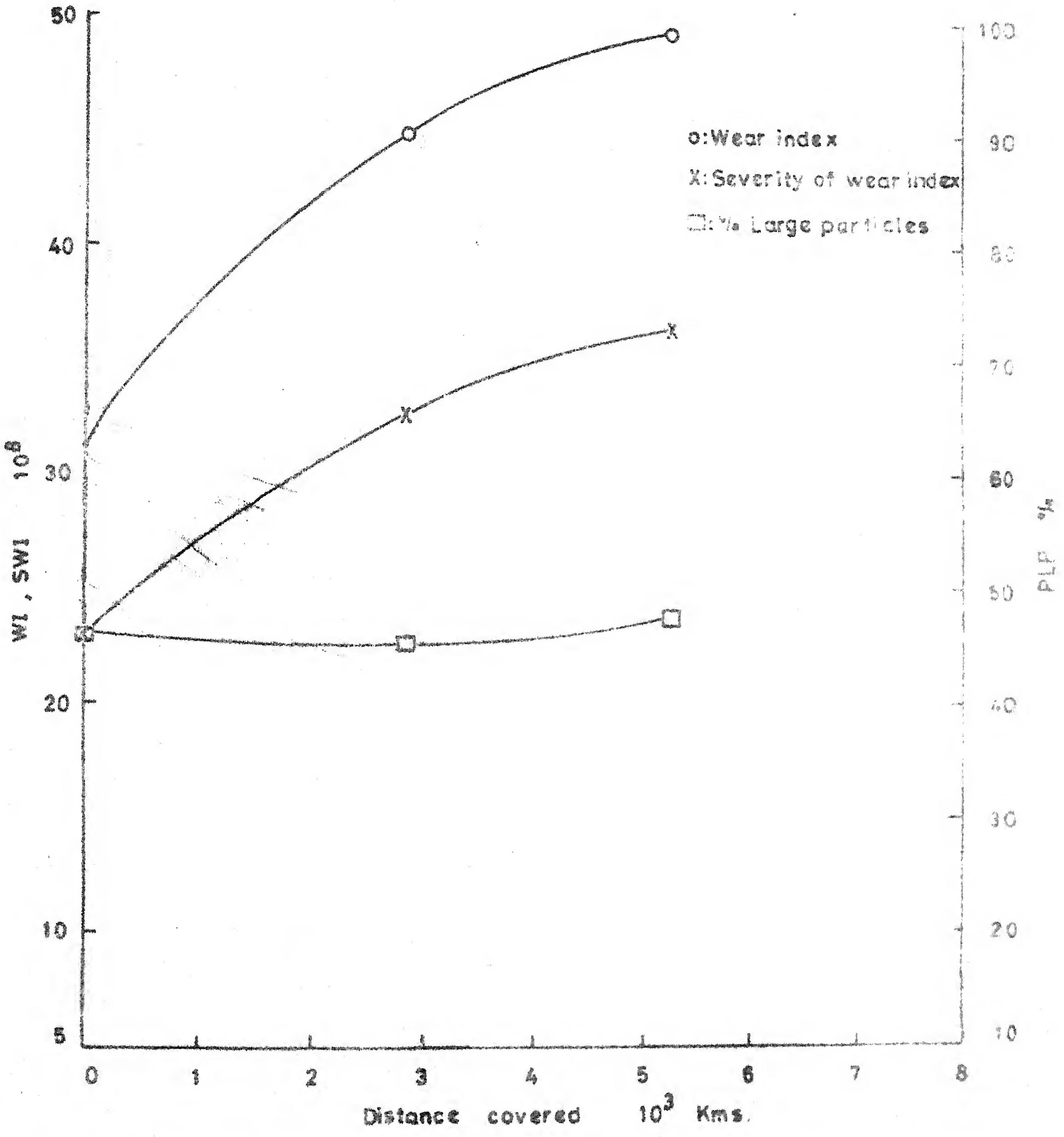

Fig. 4.8 WI ,SWI and PLP vs distance covered for bus gear box

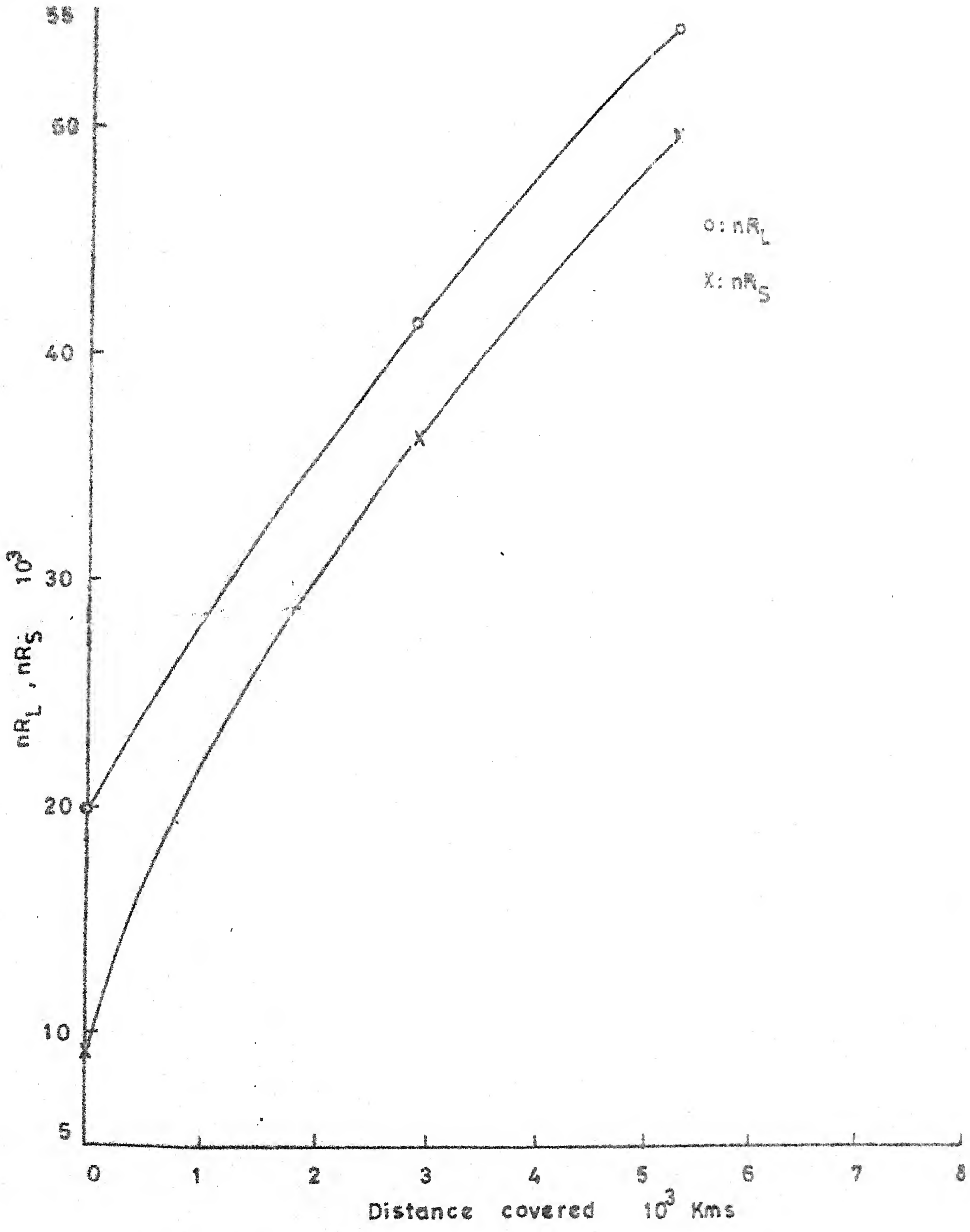

Fig. 4.9 Normalised large and small particle readings from Ferrogram.(Bus gear box).

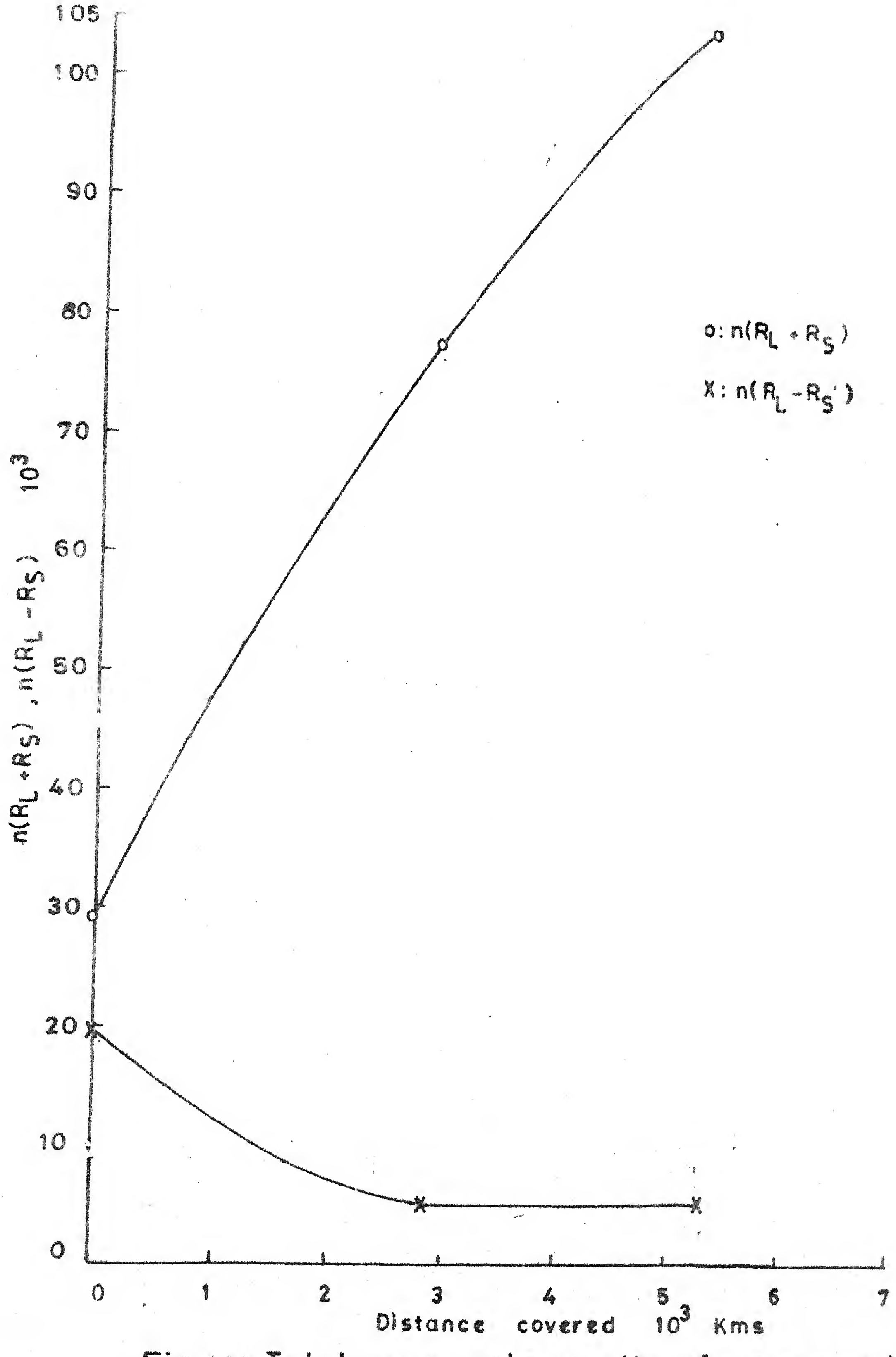

Fig.4.10 Total wear and severity of wear readings from Ferrogram. (Bus gear box).

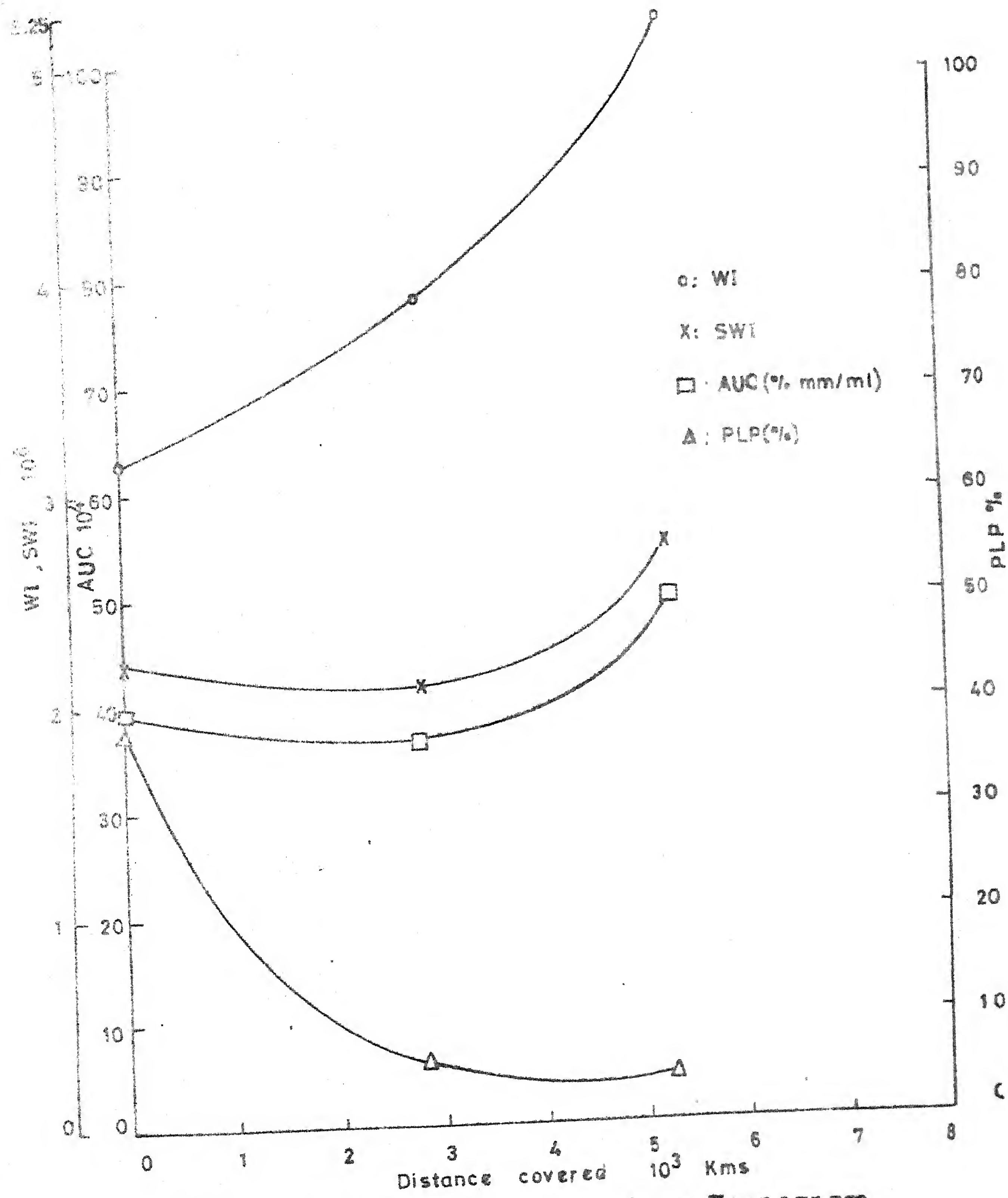

Fig.4.11: WI ,SWI ,PLP and Auc from Ferrogram readings(Busgear box).

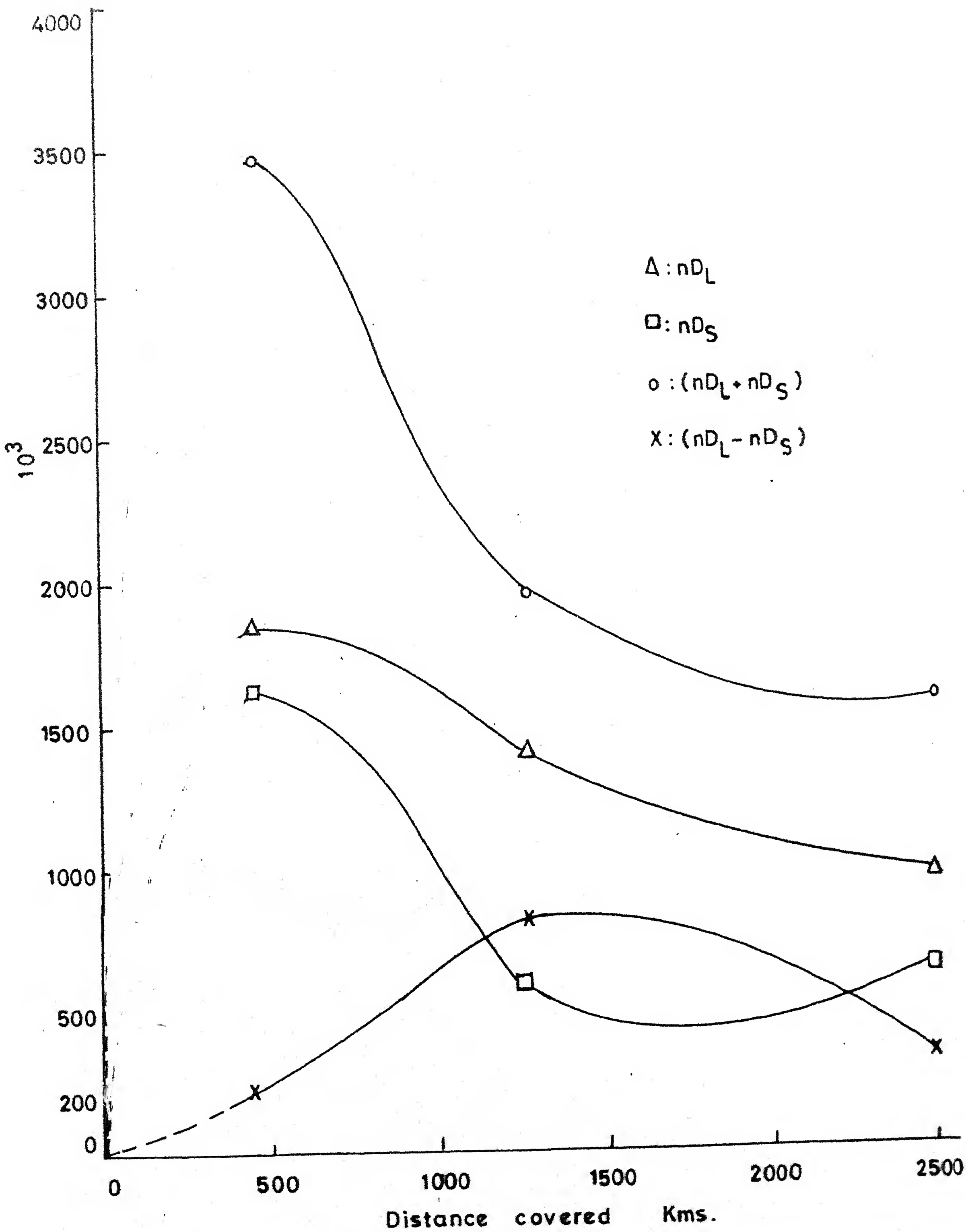

Fig.4.12 Variation of $nD_L, nD_S, n(D_L+D_S)$ and $n(D_L-D_S)$ for scooter gear box.

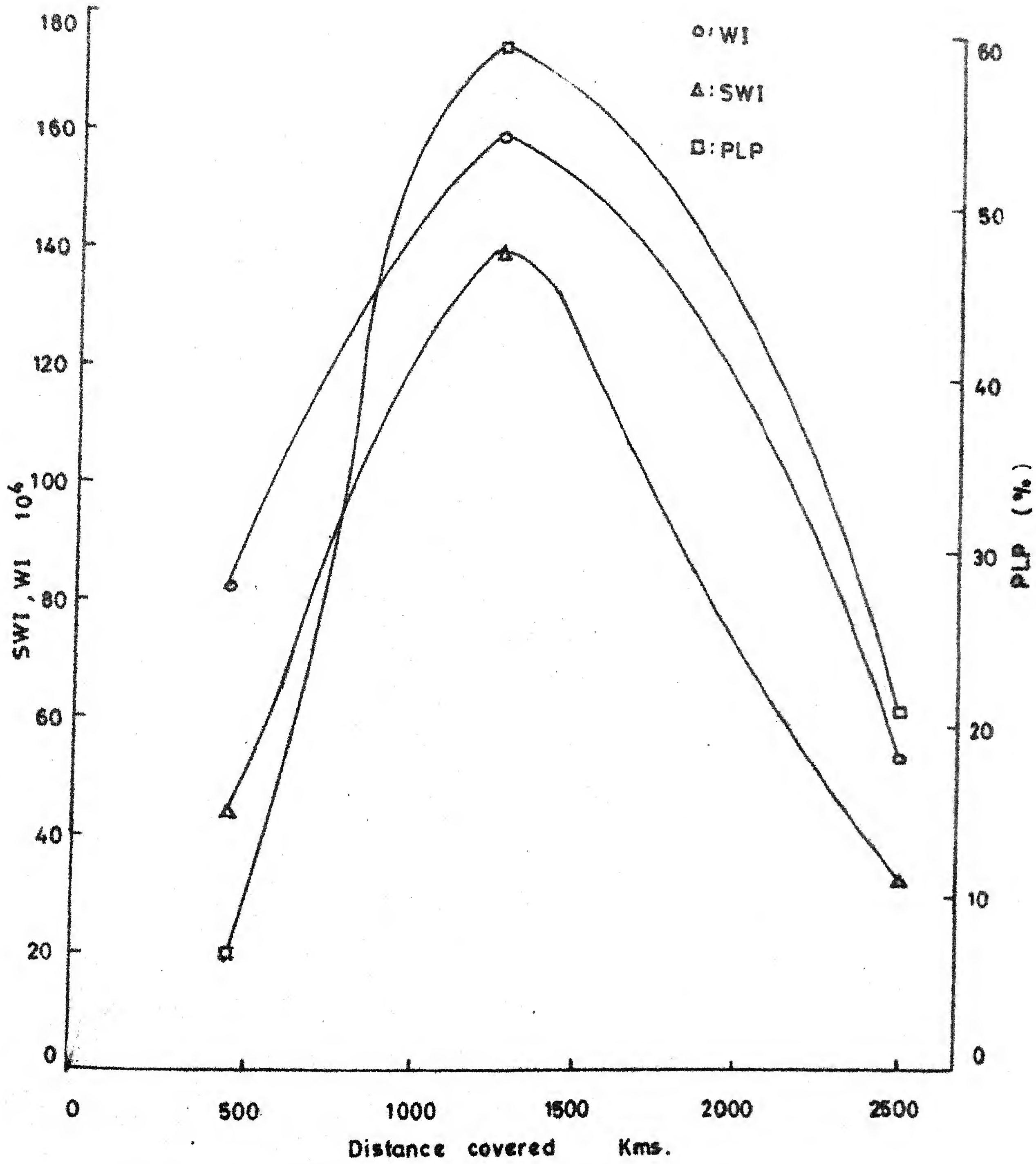

Fig. 4.13 Variation of SWI, WI and PLP for scooter gear box.

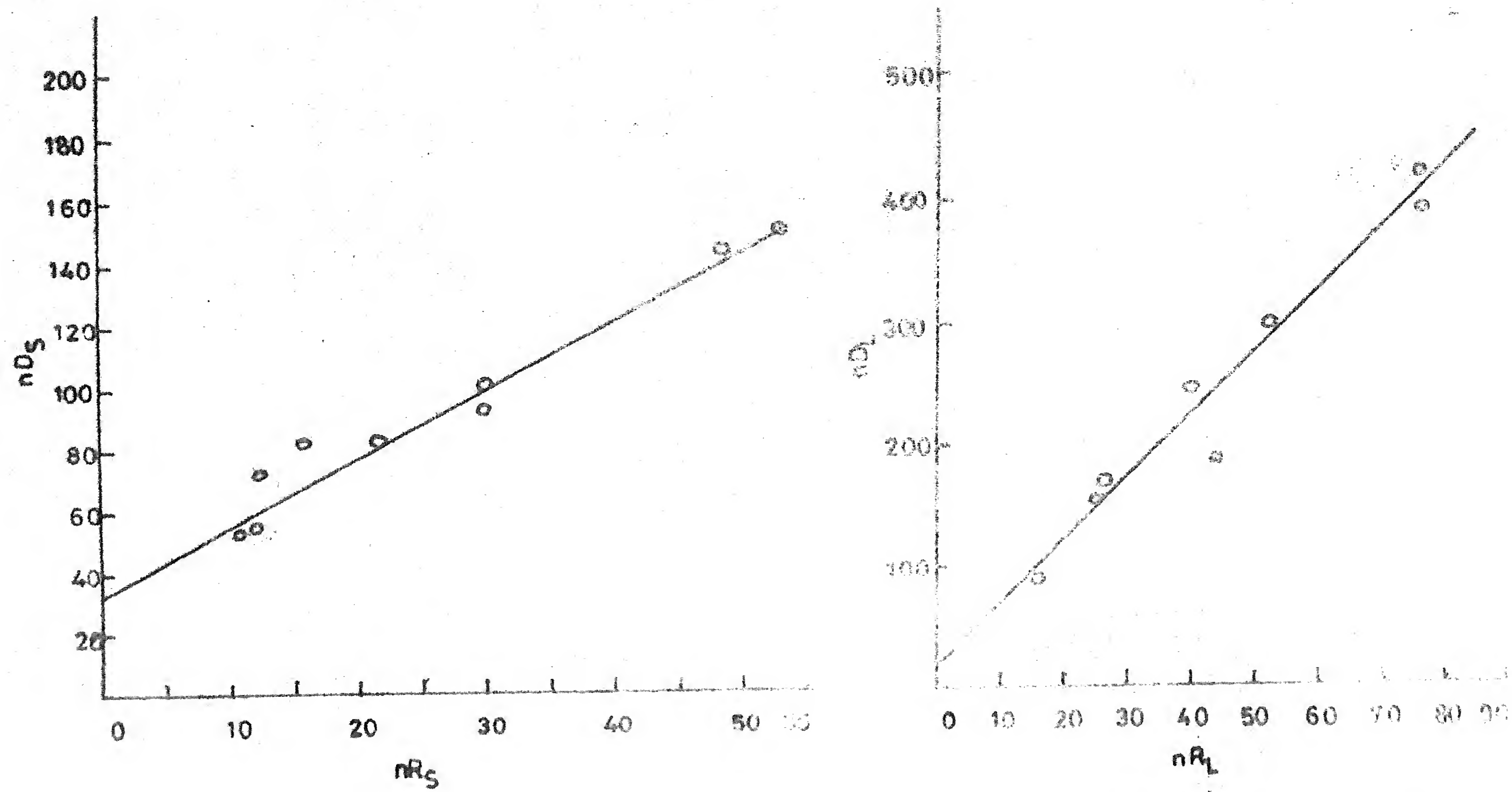

Fig. 4.14 Comparison between DR and Ferrogram readings.

(2) The technique should be applied to wear studies of simple systems whose variables like speed, load and working temperature can be controlled in the laboratory. This helps to understand the wear process under different conditions and to know the particle morphology in different systems. A wear particle 'Atlas' can be prepared for reference.

(3) The technique can be applied to various other systems like hydraulic systems, grease lubricated systems and water lubricated systems.

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APPENDIX-I

The standard specifications of the Duplex Ferrograph Analyzer.

DIRECT READER FERROGRAPH

Digital Read out	:	12.7 mm high Numitron tube display
Selector Switches	:	Power ON/OFF and particle select, L or S
Manual Adjustments	:	Lamp drive, zero adjust (large particles) and zero adjust (small particles)
Power Requirements	:	115 V ac, 60 Hz or 220 V ac, 50 Hz as specified
Cycle Time	:	5 minutes.

ANALYTICAL FERROGRAPH

Timer	:	Manually set, 0 to 15 minutes
Switch	:	ON/OFF.
Lamp	:	Cycle complete
Power Requirements	:	115 V ac, 60 Hz or 220V ac, 50 Hz as specified
Cycle Time	:	15 minutes
Overall Dimensions	:	Height, width and depth 585 x 460 x 490 mm
Mass (Duplex)	:	26.3 kg.

FERROSCOPE

Magnification	:	100 x, 400 x , 1000 x
Instant Camera	:	Polaroid, 100 x 125 mm colour photographs
35 mm Camera	:	Olympus OM 2
Filters	:	Red, green, neutral, polarizers
Mass	:	28.6 kg

FERROSCOPE CONTROLLER

Reader Display	:	12.7 mm high light omitting diode display
Switches	:	Power ON/OFF, Reflected light ON/OFF, Transmitted light ON/OFF Read ON/OFF.
Manual adjustments	:	Zero adjust (Reader) light intensity adjust (Reflected light)

APPENDIX-II

A. PROCEDURE FOR PREPARING A FERROGRAM

I Sample Preparation:

1. Oil sample is heated to 65 $\pm$ 5°C .
2. Sample is prepared by shaking the container vigorously.
3. Before each further portion is taken for testing, it is reheated and thoroughly mixed with oil.

Sample Dilution: In case of high concentration of particles to avoid pile-up a diluent is added.

II Ferrograph Preparation:

Substrate:

1. Ferrogram substrate is removed from the sealed bag and protective envelope, retaining the protective envelope for substrate storage.
2. The substrate is installed in the substrate holding fixture by retracting the spring loaded positioning pin and inserting the substrate into holding fixture as far as possible. When positioning, it is made sure that black dot appears in the lower left hand corner.

3. Then the positioning pin is gently released, making sure that the upper end of substrate is resting on the shelf and lower end resting on the magnet.

Turret Tube:

1) Turret tube is pressed into the delivery arm holding groove. Then the turret tube is extended to a distance equal to the distance from index mark to end of arm, beyond the end of delivery arm. Turret tube is pressed into the exit clamp on the downstream side of the pump.

2) Pump turret arm is released by turning the knurled nut counterclockwise. Then pump turret arms are opened, tube is threaded around the turret and then turret tube, they are not clamped and neither the turret arms are tightened until after the motor is started.

3) Turret tube is pressed into the pump entry tube clamp on the upstream side of pump and is secured by turning the knurled eccentric clamp lever counter.

4) Suction end of the turret tube is placed temporarily in the spring clip, it ultimately goes to sample vial. The delivery end of turret tube is already pressed into the holding groove of delivery arm.

Drain Tube:

1) The drain tube is inspected, plugs of liquid, if any are drawn out by a cotton swab.

2) The drain tube is then inserted into the drain tube-holder.

3) Drain tube holding fixture is rotated counter-clockwise until it is centred on the substrate.

4) Notched end of tube is then lowered until it touches the substrate and then drain tube is pushed forward to the limit of the notch.

III Preparation of Liquid:

In this section procedure adopted for mixing the various liquids has been described.

1) The fixer/oil bottle cap is removed and 1 ml. dispenser assembly is attached to the fixer/oil bottle.

2) Five ml. of fixer/oil is discharged into sample vial.

3) The sample vial containing the 5 ml. of fixer/oil is placed into the vial rack slot nearest the magnet assembly.

4) One ml. of fixer/oil is discharged into a second sample vial and placed in one of the empty vial rack slots.

5) Using the precision pipettor 1 ml of sample oil is withdrawn and discharged into the sample vial containing 1 ml. of fixer/oil. Repeating twice, the sample vial is filled with 3 ml. of oil sample.

While using pipettor, following instructions are followed:

(a) Pipette tip is installed.

(b) Plunger is pushed in 2 stops.

(c) The tip is inserted into liquid and plunger is released to draw liquid up.

(d) One ml. of liquid is delivered by pushing the plunger down to first stop.

(e) Another ml. of liquid may be delivered by repeating the process starting at step '6'

6) The sample and fixer are mixed thoroughly in the vial by shaking it vigorously.

7) Sample vial is placed back into rack to avoid the influence of field strength of the magnet.

Sample is run as soon as the sample is mixed to avoid particle settling.

8) Spring clip assembly is installed on the oil sample vial.

9) Suction end of the turret tube is inserted into the bottom of the sample vial and the tube is pressed

into the spring clip.

10) Delivery arm is lowered until the exit end of the tube touches the substrate. Then delivery arm is backed off by approximately 1 mm, so that liquid does not trip but flows freely onto the substrate.

IV Operating Procedure:

Startup

1) Power switch is placed on 'ON' position.

2) Timer is set to 15 minutes.

3) Red timer button is depressed to start the sample cycle.

4) Pump turret arms are clamped and tightened by turning the knurled nut on the locking screw clockwise.

Sample and Fixer Oil Flow:

1) The sample oil takes about 10 minutes to run.

2) When the sample vial is empty, timer is reset to 10 mins.

3) Red time START button is depressed to start the wash cycle

4) Spring clip and turret tube are removed from the empty vial and both are transferred to the vial containing the fixer/oil.

5) Three air gaps are introduced into flow in the turret tube by removing the end of the turret tube, momentarily from the fixer/oil solution and then reinserting back into the solution. This prevents oil from diffusing back.

Shut Down:

1) Immediately after the pump shuts off, the turret tube of the ferrogram is lifted by raising the delivery arm.

2) When flow through drain tube has stopped, after approximately one minute, the drain tube holder is lifted with drain tube in it and rotated by 90° clockwise.

3) Sufficient time is allowed for the ferrogram to dry. Ferrogram is not removed until all the fixer/oil has evaporated.

4) Spring loaded position pin is released and ferrogram is lifted up vertically.

Ferrogram is not drawn across magnet as that can disturb the particles.

5) Ferrogram is labelled on the top surface upper right hand corner.

6) Turret tube is discarded along with the sample and fixer/oil vials.

7) Liquid from the waste bottle is also discarded .

B. SAMPLE PROCESSING WITH DIRECT READING FERROGRAPH

I Calibration Check :

The calibration check procedure can be found in the technical information provided by Foxboro Company.

Start-Up:

1) The power cord is connected to the appropriate power line.

2) Power switch is placed to the 'ON' position.

3) System is allowed to warm up for 30 minutes before proceeding further.

II Sample Preparation:

Sample Vial Holder:

1) The post bracket is adjusted to the recommended height for a consistent flow rate by aligning the post bracket set screw with the hole in support stand. Set screw is tightened.

2) Sample vial holder is placed in the post bracket.

Precipitator Tube Installation:

1) Precipitator tube is removed from the sealed envelope. Envelope is retained for later use.

2) Using the spring clamp lever the precipitator tube assembly is lifted sufficiently to allow the installation of the glass tube in channel under the clamp.

3) Capillary tube is threaded through the cleat at the base of support stand. The suction end of the capillary tube is temporarily inserted in the space between the support stand and capillary tube holding clip.

4) The end of the clear flexible discharge tube is pushed over the inlet to drain.

5) An empty waste bottle is placed in the waste bottle holder.

Preparing the Sample for Running:

1) Sample vial is placed in the sample vial holder.

2) Fixer/oil bottle cap is removed and 1 ml. dispenser assembly is attached to fixer/oil bottle.

3) One ml. of the fixer/oil is discharged into the sample vial.

4) If the sample has not been recently obtained from the equipment being monitored, the sample is heated and shaken.

5) Using pipettor with a clean pipette tip attached, 1 ml. of oil is withdrawn from the sample bottle and discharged into the sample vial which already contains 1 ml.

of fixer/oil pipette tip is discarded.

6) For thoroughly mixing the sample and solvent in the vial, vial is shaken vigorously with hand.

7) Sample vial is placed in the holder.

8) Suction end of the tube is removed from between the support-stand and the capillary tube holding clip.

9) The capillary tube is inserted into the bottom of sample vial.

10) The capillary tube is pressed into the holding clip above the sample vial.

The sample must be run soon after mixing. If solution is allowed to remain in the vial, particles settling will reduce the readings because of particle settling.

III Operating Procedure:

Starting Sample Flow:

1) The drain bulb is squeezed and the drain outlet is covered with a piece of plastic from the precipitator tube envelope.

2) The bulb is released while maintaining the seal on the drain outlet.

3) When the sample from the vial flows down to the capillary tube cleat the plastic from the drain tube outlet is removed.

4) The flow of oil into the precipitator tube is observed. When the liquid has passed the light path D_L reading will undergo a large change.

5) It is checked whether the D_S reading has undergone a similar change.

Zero Adjustments:

1) When the liquid just passes the light paths, the flow is stopped by crimping the plastic drain tube where it connects to the drain inlet.

2) The particle select switch is placed in the L position.

3) The lamp drive potentiometer is adjusted to obtain a coarse zero reading within the range of 0.0 ± 10.0. The control is locked.

4) The L zero adjust potentiometer is adjusted until the display reads 0.0 ± 0.2 and the control is locked.

5) The particle select switch is placed in the S position.

6) The S zero adjust potentiometer is adjusted to get a display of 0.0 $\pm$ 0.2 and the control is locked.

7) The plastic drain tube is uncrimped to run the sample.

Sample Flow and Recording:

The time required for an oil sample to flow through the system depends upon the oil viscosity. Typical time for sample flow is 4 minutes.

1) When the liquid stops flowing, the particle select switch is placed in the L position and the reading D_L is recorded.

2) The particle select switch is placed in the S position and the D_S reading is recorded.

OPAQUE OIL SAMPLING PROCEDURE:

Preparation:

1) A second sample holder assembly is installed on the support stand just above the first holder. It is rotated to 45°, approximately, to the first holder.

2) A second sample vial is filled with fixer/oil and placed in the second sample holder. This is used for zeroing and flushing.

3) The precipitator tube is installed as described before, but the suction end of the capillary tube is

Operation:

1) The flow of fixer/oil is initiated in the precipitator tube.

2) The zero adjustment is performed when the fixer/oil passes the L and S light paths.

3) The capillary tube is removed from the fixer/oil and stored temporarily between the support stand and the capillary tube holding clip.

4) The sample vial containing the prepared sample is placed in the lower sample holder.

5) The suction end of the capillary tube is inserted to the bottom of the sample vial containing the prepared sample and the flow is initiated.

6) When the last of the sample in the vial is drawn up into the capillary tube, the capillary tube is quickly removed from the oil sample vial and placed into the vial containing fixer/oil. It is important not to lose the siphon in the capillary tube. If the siphon is lost, flow is reestablished by gently squeezing and very gently releasing the squeeze bulb so that surges in the precipitator tube are minimized.

7) As the fixer/oil flows through the precipitator tube, air gaps are introduced every 5 to 10 seconds by

briefly lifting the suction end of the capillary tube. The readings rise when the air gap passes the light paths and then the readings will either decrease or be about the same as before. If the readings are no longer reduced significantly when the air gaps pass the sensors, the capillary tube is removed from the fixer/ oil vial to stop the flow.

8) The D_L and D_S readings are recorded.

C PROCEDURE FOR PUTTING THE FERROSCOPE INTO OPERATION:

(1) The voltage selector switch is matched to local mains voltage.

(2) The light source is switched on.

(3) A specimen slide is placed on the mechanical stage.

(4) The coarse focussing is done with 10X objective.

(5) The interpupillary distance and diopter adjustments are made.

(6) The condenser position is adjusted.

(7) The desired objective is swung in position.

(8) The light intensity is adjusted.

(9) Fine focussing is done.

(10) The aperture iris diaphragm and field iris diaphragm are adjusted.

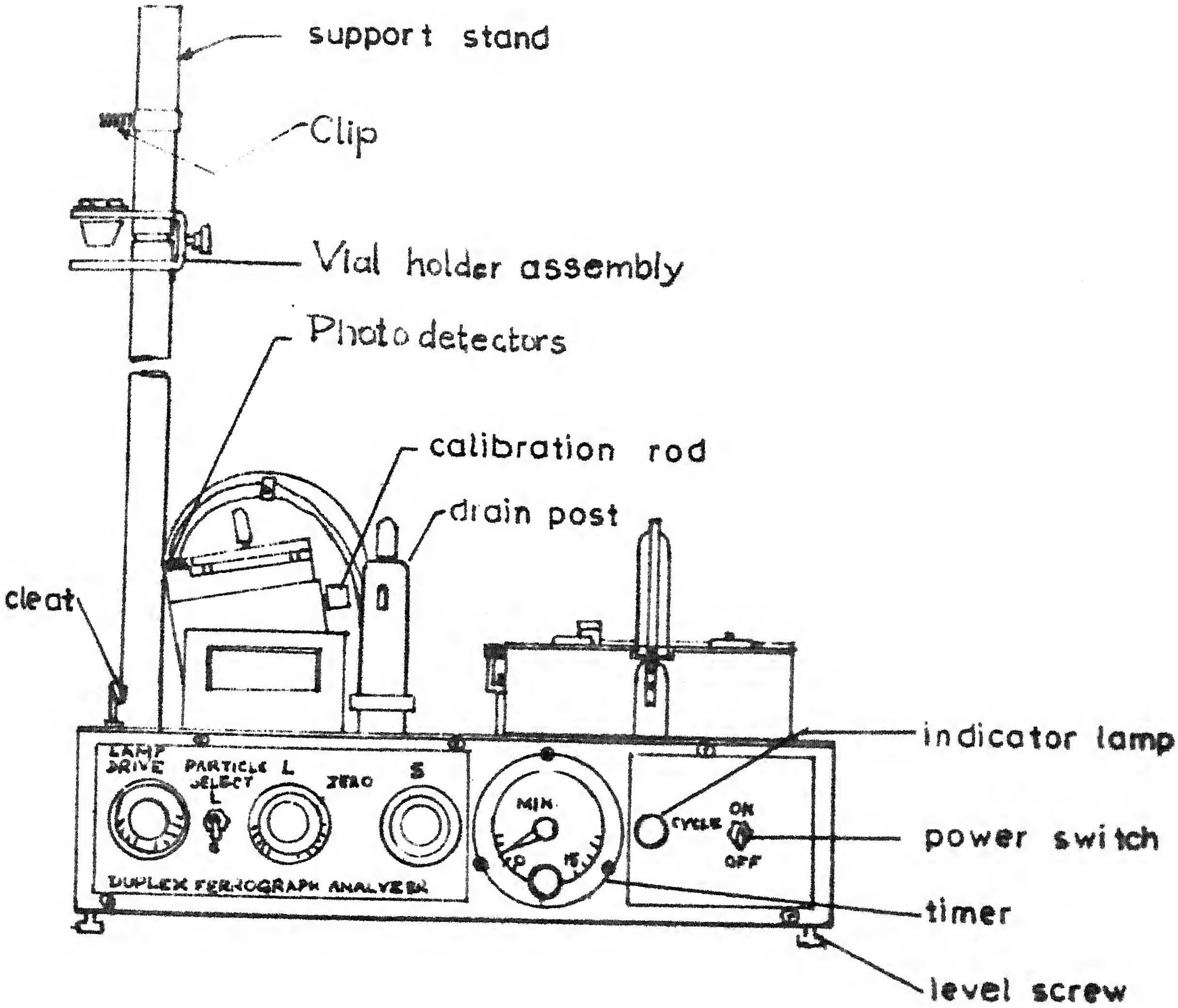
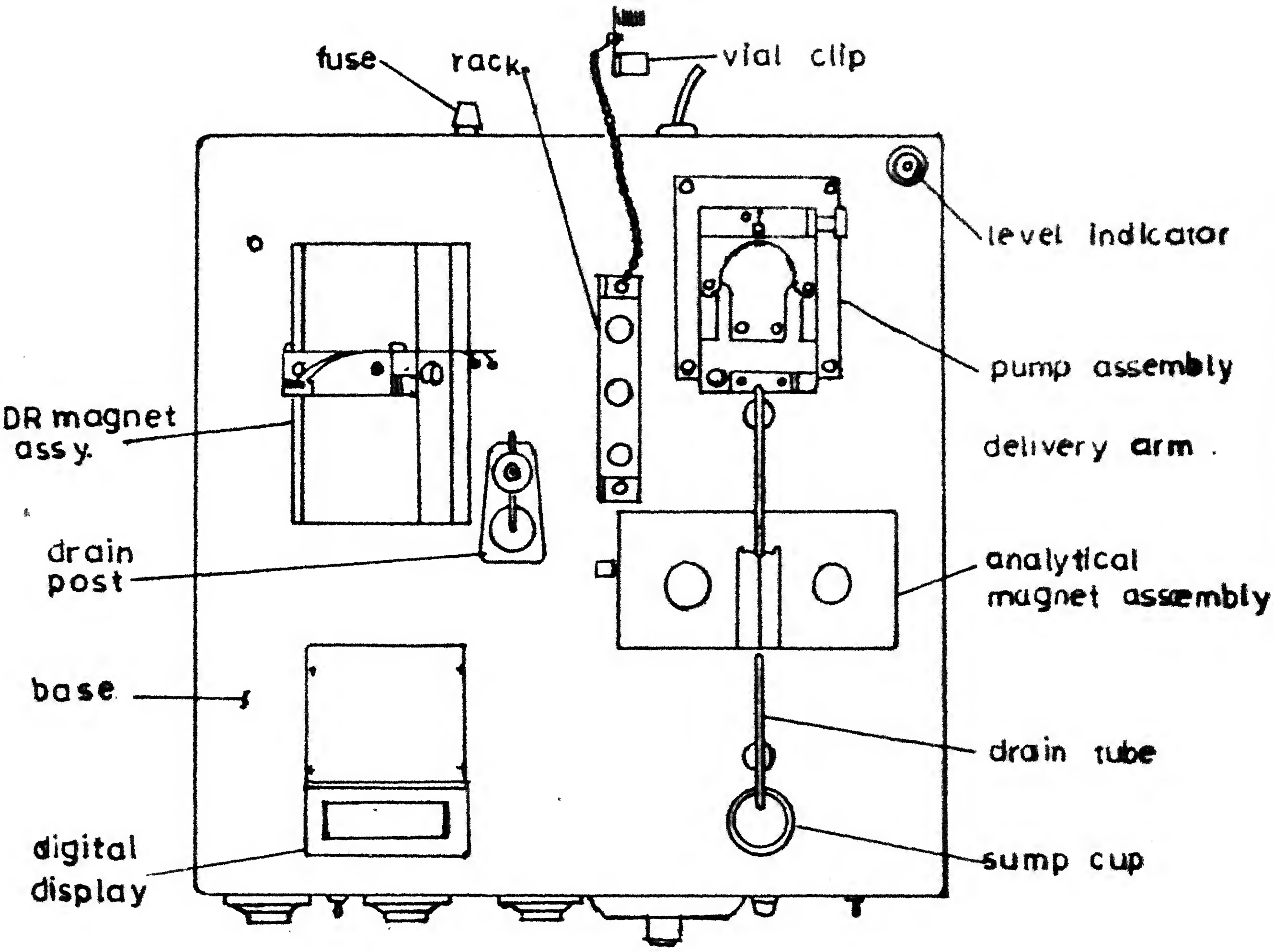


Fig. II-1 Duplex Ferrograph Analyzer - Front View



FigII-2 Duplex Ferrograph Analyzer - Top View

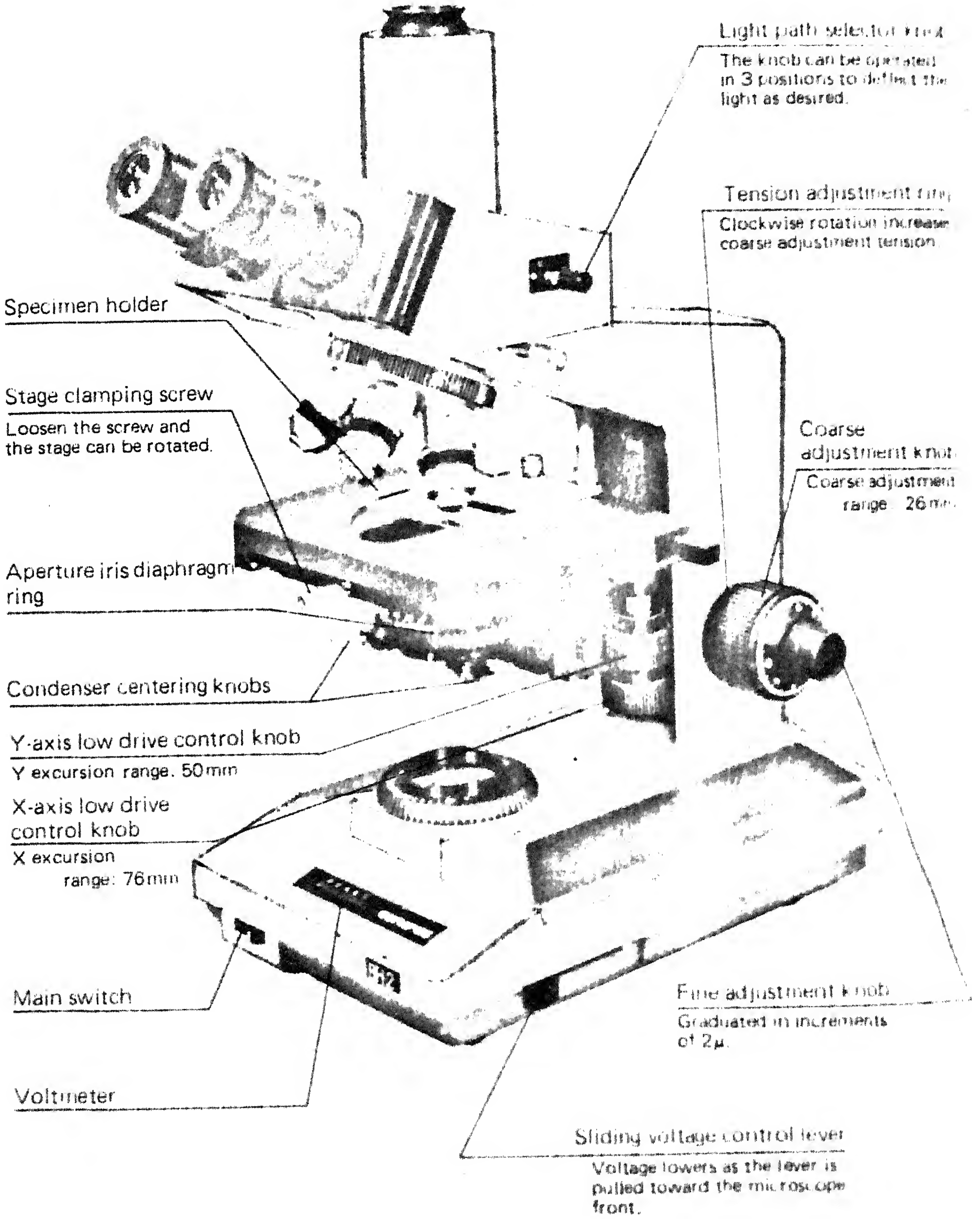


Fig-II-3. Ferroscope

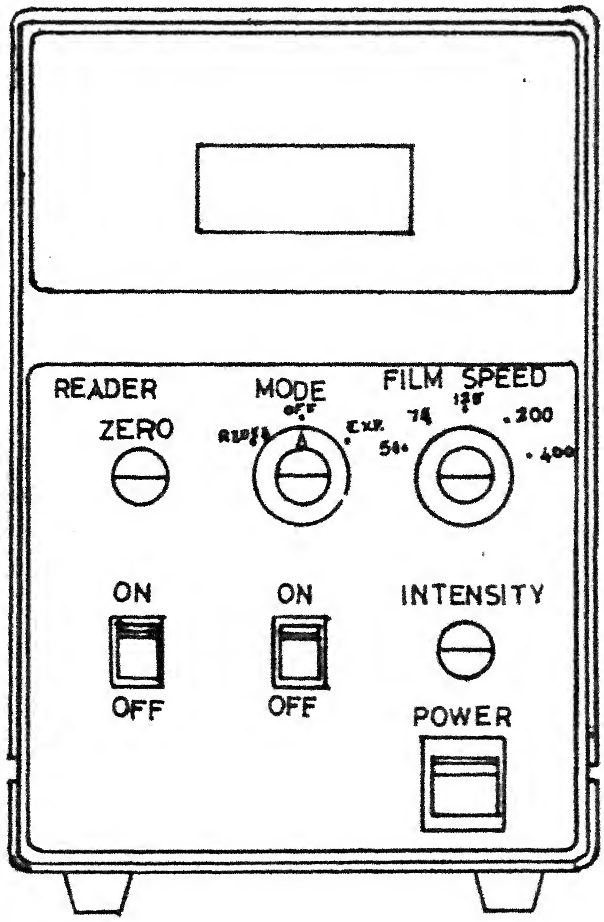


Fig.II-4 Ferroscope Controller- Front Panel

APPENDIX-III

SPECIMEN CALCULATIONS

Sample No. 2 of the diesel engine is considered. The dilution ratio used is 1:3 (1 ml oil sample in 3 ml of mixture).

Therefore $n = 3$

Direct Reader Calculations:

SWI, WI and PLP :

$D_L = 81.8$

$D_S = 27.5$

The normalized readings are $nD_L = 3 \times 81.8 = 245.4$

$nD_S = 3 \times 27.5 = 82.5$

The total wear $= nD_L + bD_S$

$= 245.4 + 82.5$

$= 327.9$

The wear index $WI = (nD_L + nD_S)\ (nD_L - nD_S)$

$= 327.9 \times 162.9$

$= 53.415 \times 10^3$

The severity of wear index $SWI = nD_L\ (nD_L - nD_S)$

$= (245.4 \times 162.9)$

The percentage large particles PLP $= \dfrac{nD_L - nD_S}{nD_L + nD_S} \times 100$

$$= \frac{162.9}{327.9} \times 100$$

$$= 49.69\%$$

The Ferrogram Reader Calculations:

Sample 2 with the same dilution of 1:3 was used for preparing the ferrogram. The volume of liquid (n_1) used for the ferrogram preparation was 3 ml.

Hence, $n = 3$

$n_1 = 3$

Area Under the Curve : The Reader readings at various position are as follows.

$R_{10} = 31.9$, $R_{20} = 24.7$, $R_{30} = 21.73$,

$R_{40} = 25.6$, $R_{50} = 18.5$

$R_L = 39.6$

The normalized 'percentage area covered' reading for 10 mm position is

$$R'_{10} = \frac{R_{10} \times n}{n_1}$$

$$= \frac{31.9 \times 3}{3} = 31.9$$

Hence $R'_{10} = R_{10}$

$R'_{20} = R_{20}$ and so on.

Now, the percentage area covered reading for the segment between 10 mm position to 20 mm position is given by,

$$A_1 = \frac{R'_{20} + R'_{10}}{2} \times 10 \text{ mm}$$

$$= \frac{R_{20} + R_{10}}{2} \times 10 \text{ mm}$$

$$= \frac{24.7 + 31.9}{2} \times 10$$

$$= 283 \ \frac{\% \text{ mm}}{\text{ml}}$$

Similarly

$$A_2 = 232.95$$

$$A_3 = 236.60$$

$$A_4 = 220.50$$

$$A_5 = 232.4$$

The 'Area Under the Curve' for the whole Ferrogram is

$$AUC = A_1 + A_2 + A_3 + A_4 + A_5$$

$$= 283 + 232.95 + 236.60 + 220.50 + 232.4$$

$$= 1204.65 \ \frac{\% \text{ mm}}{\text{ml}}$$

SWI, WI and PLP:

The reading at the entry deposit $R_L = 39.6$

The reading at 5 mm downstream from the entry position $R_S = 15.63$

The normalized R_L is $nR_L = 39.6 \times 3 = 113.8$

The normalized R_S is $nR_S = 15.63 \times 3 = 46.89$

The total wear $= nR_L + nR_S$

$= 165.69$

The severity of wear $= nR_L - nR_S$

$= 113.8 - 46.89$

$= 71.91$

The Wear Index WI $= n(R_L + R_S) \times n\,(R_L - R_S)$

$= 118.8 \times 46.89$

$= 11.9133 \times 10^3$

Severity of Wear Index SWI $= nR_L(nR_L - nR_S)$

$= 113.8 \times 71.91$

$= 3.543 \times 10^3$

Percentage Large Particle

PLP $= \dfrac{nR_L - nR_S}{nR_L + nR_S} \times 100$

$= \dfrac{71.91}{165.69} \times 100$

$= 43.40\%$

APPENDIX-IV

DETAILS OF TATA 1210 SE VEHICLE ENGINE AND GEAR BOX

Engine:

Type	:	Inline 6 cylinder, water cooled, Direct injection diesel engine
Model	:	692 D.I.
Bore/Stroke	:	92 mm/120 mm
Capacity (swept volume)	:	4783 cc
Compression pressure at 150-200 rpm	:	At least 20 kg/cm^2
Maximum Torque (Standard Engine)	:	30 mkg at 1300 to 2000 rpm.
Oil Filter	:	Full flow replaceable paper cartridge
Crank-case Oil Capacity	:	12 litres (min.) to 14 litres (max.)
Engine Oil used (crank-case Oil)	:	Servo Super 30 (Indian Oil) conforming to MIL-L-2104B-engine oils (SAE 30)
Oil change	:	For every 9000 kms.
Filter Cartridge change	:	For every 9000 kms.

Gear Box:

GBC 30 Gear box, with 5 forward and 1 reverse speeds.

1st, 2nd, 3rd and 4th	Constant mesh
5th	Direct drive
Reverse	Sliding mesh
Gear box oil used	Servo Gear Super-90 (Indian Oil) Conforming to MIL-L-2105B
Gear oil change	18000 kms.

Date Slip

This book is to be returned on the date last stamped.